Refine Search

Search Results -

Terms	Documents
5280431.pn. and (simult$ or ((happen$ or done) with "same" with time))	1

Database:

US Pre-Grant Publication Full-Text Database
US Patents Full-Text Database
US OCR Full-Text Database
EPO Abstracts Database
JPO Abstracts Database
Derwent World Patents Index
IBM Technical Disclosure Bulletins

Search: L32

Refine Search

Recall Text Clear Interrupt

Search History

DATE: Monday, January 22, 2007 **Purge Queries** Printable Copy Create Case

Set Name side by side	**Query**	**Hit Count**	**Set Name** result set
	DB=USPT; THES=ASSIGNEE; PLUR=YES; OP=OR		
L32	5280431.pn. and (simult$ or ((happen$ or done) with "same" with time))	1	L32
L31	5281901.pn. and (simult$ or ((happen$ or done) with "same" with time))	1	L31
	5283739.pn. and (simult$ or ((happen$ or done)		

L30	with "same" with time))	1	L30
L29	5341130.pn. and (simult$ or ((happen$ or done) with "same" with time))	1	L29
L28	5650703.pn. and (simult$ or ((happen$ or done) with "same" with time))	1	L28

DB=PGPB; THES=ASSIGNEE; PLUR=YES; OP=OR

L27	L26	1	L27
L26	20040046545 and (simult$ or ((happen$ or done) with "same" with time))	1	L26

DB=PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD; THES=ASSIGNEE; PLUR=YES; OP=OR

L25	L23 and (simult$ or ((happen$ or done) with "same" with time))	14	L25
L24	L23 and (simult$ or ((happen$ or done) with "same" with time))	14	L24
L23	L21 or L22	33	L23
L22	L20 and @pd<=20031014	26	L22
L21	L20 and @ad<=20031014	32	L21
L20	L5 and (control$ with ((2$ or two$) near2 AGV$))	37	L20
L19	L5 and (mov$ with ((2$ or two$) near2 AGV$))	0	L19
L18	L5 and (simul$ same ((2$ or two$) near2 AGV$))	0	L18
L17	L5 and (simul$ near4 mov$) and (single$ with (path$ or way$))	0	L17
L16	L5 and (simul$ near4 mov$) and (single with (path$ or way$))	0	L16
L15	L5 and (simultaneous$ near2 mov$) and (single with (path$ or way$))	0	L15
L14	L5 and (simultaneous$ near2 mov$) and (single near2 (path or way))	0	L14
L13	L11 and ((("same" with tim$) or simulta$) with mov$)	0	L13
L12	L11 and (simulta$ with mov$)	0	L12

L11	L9 and L10	1	L11
L10	6049745.pn.	2	L10
L9	L7 or L8	242	L9
L8	L6 and @pd<=20031014	194	L8
L7	L6 and @ad<=20031014	242	L7
L6	(agv$ or (automat$ adj guid$ adj vehicl$)).clm.	277	L6
L5	agv$ or (automat$ adj guid$ adj vehicl$)	5362	L5
DB=PGPB; THES=ASSIGNEE; PLUR=YES; OP=OR			
L4	L3 and simultan$	1	L4
L3	20050080524	1	L3
DB=USPT; THES=ASSIGNEE; PLUR=YES; OP=OR			
L2	L1 and (ttl$ or thin$)	1	L2
L1	5526022.pn.	1	L1

END OF SEARCH HISTORY

Hit List

First Hit
Your wildcard search against 10000 terms has yielded the results below.

Your result set for the last L# is incomplete.

The probable cause is use of unlimited truncation. Revise your search strategy to use limited truncation.

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs
Generate OACS

Search Results - Record(s) 11 through 14 of 14 returned.

☐ 11. Document ID: US 4926103 A

L25: Entry 11 of 14 File: USPT May 15, 1990

US-PAT-NO: 4926103
DOCUMENT-IDENTIFIER: US 4926103 A

TITLE: System for dynamically determining position of multiple automatically guided vehicles

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 12. Document ID: US 4780817 A

L25: Entry 12 of 14 File: USPT Oct 25, 1988

US-PAT-NO: 4780817
DOCUMENT-IDENTIFIER: US 4780817 A

TITLE: Method and apparatus for providing destination and vehicle function information to an automatic guided vehicle

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 13. Document ID: US 4530056 A

L25: Entry 13 of 14 File: USPT Jul 16, 1985

US-PAT-NO: 4530056
DOCUMENT-IDENTIFIER: US 4530056 A

TITLE: Automated guided vehicle system

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☐ 14. Document ID: JP 10031515 A

L25: Entry 14 of 14 File: JPAB Feb 3, 1998

PUB-NO: JP410031515A
DOCUMENT-IDENTIFIER: JP 10031515 A
TITLE: CONTROL METHOD FOR AUTOMATED GUIDE VEHICLE AND AUTOMATED GUIDED DEVICE

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs | Generate OACS

Terms	Documents
L23 and (simult$ or ((happen$ or done) with "same" with time))	14

Display Format: [-] Change Format

Previous Page   Next Page   Go to Doc#

Hit List

First Hit
Your wildcard search against 10000 terms has yielded the results below.

Your result set for the last L# is incomplete.

The probable cause is use of unlimited truncation. Revise your search strategy to use limited truncation.

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs | Generate OACS

Search Results - Record(s) 1 through 10 of 14 returned.

☐ 1. Document ID: US 20040046545 A1

L25: Entry 1 of 14 File: PGPB Mar 11, 2004

PGPUB-DOCUMENT-NUMBER: 20040046545
PGPUB-FILING-TYPE: new
DOCUMENT-IDENTIFIER: US 20040046545 A1

TITLE: Conveyance system, conveyance method and vacuum holding apparatus for object to be processed, and centering method for water

PUBLICATION-DATE: March 11, 2004

INVENTOR-INFORMATION:

NAME	CITY	STATE	COUNTRY
Akiyama, Shuji	Nirasaki-Shi		JP
Iijima, Toshihiko	Nirasaki-Shi		JP
Hosaka, Hiroki	Nirasaki-Shi		JP

US-CL-CURRENT: 324/158.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KMC | Draw. D

☐ 2. Document ID: US 5650703 A

L25: Entry 2 of 14 File: USPT Jul 22, 1997

US-PAT-NO: 5650703
DOCUMENT-IDENTIFIER: US 5650703 A
**** See image for Certificate of Correction ****
**** See image for Reexamination Certificate ****

TITLE: Downward compatible AGV system and methods

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Drawn D

☐ 3. Document ID: US 5341130 A

L25: Entry 3 of 14 File: USPT Aug 23, 1994

US-PAT-NO: 5341130
DOCUMENT-IDENTIFIER: US 5341130 A

TITLE: Downward compatible AGV system and methods

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Drawn D

☐ 4. Document ID: US 5283739 A

L25: Entry 4 of 14 File: USPT Feb 1, 1994

US-PAT-NO: 5283739
DOCUMENT-IDENTIFIER: US 5283739 A

TITLE: Static collision avoidance method for multiple automatically guided vehicles

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Drawn D

☐ 5. Document ID: US 5281901 A

L25: Entry 5 of 14 File: USPT Jan 25, 1994

US-PAT-NO: 5281901
DOCUMENT-IDENTIFIER: US 5281901 A
**** See image for Certificate of Correction ****

TITLE: Downward compatible AGV system and methods

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Drawn D

☐ 6. Document ID: US 5280431 A

L25: Entry 6 of 14 File: USPT Jan 18, 1994

US-PAT-NO: 5280431
DOCUMENT-IDENTIFIER: US 5280431 A

TITLE: Method for controlling the movements of a mobile robot in a multiple node factory

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 7. Document ID: US 5163001 A

L25: Entry 7 of 14 File: USPT Nov 10, 1992

US-PAT-NO: 5163001
DOCUMENT-IDENTIFIER: US 5163001 A

TITLE: Interactive display for use on an automatic guided vehicle

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 8. Document ID: US 5091855 A

L25: Entry 8 of 14 File: USPT Feb 25, 1992

US-PAT-NO: 5091855
DOCUMENT-IDENTIFIER: US 5091855 A

TITLE: Operation control system for automated guide vehicles

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 9. Document ID: US 5075853 A

L25: Entry 9 of 14 File: USPT Dec 24, 1991

US-PAT-NO: 5075853
DOCUMENT-IDENTIFIER: US 5075853 A

TITLE: Replaceable vehicle control prom

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 10. Document ID: US 5023790 A

L25: Entry 10 of 14 File: USPT Jun 11, 1991

US-PAT-NO: 5023790
DOCUMENT-IDENTIFIER: US 5023790 A

TITLE: Automatic guided vehicle system

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs | Generate OACS

Terms	Documents
L23 and (simult$ or ((happen$ or done) with "same" with time))	14

Display Format: - Change Format

Previous Page   Next Page   Go to Doc#

Hit List

First Hit
Your wildcard search against 10000 terms has yielded the results below.

Your result set for the last L# is incomplete.

The probable cause is use of unlimited truncation. Revise your search strategy to use limited truncation.

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs | Generate OACS

Search Results - Record(s) 1 through 10 of 14 returned.

☐ 1. Document ID: US 20040046545 A1

L25: Entry 1 of 14 File: PGPB Mar 11, 2004

PGPUB-DOCUMENT-NUMBER: 20040046545
PGPUB-FILING-TYPE: new
DOCUMENT-IDENTIFIER: US 20040046545 A1

TITLE: Conveyance system, conveyance method and vacuum holding apparatus for object to be processed, and centering method for water

PUBLICATION-DATE: March 11, 2004

INVENTOR-INFORMATION:

NAME	CITY	STATE	COUNTRY
Akiyama, Shuji	Nirasaki-Shi		JP
Iijima, Toshihiko	Nirasaki-Shi		JP
Hosaka, Hiroki	Nirasaki-Shi		JP

US-CL-CURRENT: 324/158.1

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Draw. D

☐ 2. Document ID: US 5650703 A

L25: Entry 2 of 14 File: USPT Jul 22, 1997

US-PAT-NO: 5650703
DOCUMENT-IDENTIFIER: US 5650703 A
**** See image for Certificate of Correction ****
**** See image for Reexamination Certificate ****

TITLE: Downward compatible AGV system and methods

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☐ 3. Document ID: US 5341130 A

L25: Entry 3 of 14 File: USPT Aug 23, 1994

US-PAT-NO: 5341130
DOCUMENT-IDENTIFIER: US 5341130 A

TITLE: Downward compatible AGV system and methods

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☐ 4. Document ID: US 5283739 A

L25: Entry 4 of 14 File: USPT Feb 1, 1994

US-PAT-NO: 5283739
DOCUMENT-IDENTIFIER: US 5283739 A

TITLE: Static collision avoidance method for multiple automatically guided vehicles

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☐ 5. Document ID: US 5281901 A

L25: Entry 5 of 14 File: USPT Jan 25, 1994

US-PAT-NO: 5281901
DOCUMENT-IDENTIFIER: US 5281901 A
**** See image for Certificate of Correction ****

TITLE: Downward compatible AGV system and methods

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☐ 6. Document ID: US 5280431 A

L25: Entry 6 of 14 File: USPT Jan 18, 1994

US-PAT-NO: 5280431
DOCUMENT-IDENTIFIER: US 5280431 A

TITLE: Method for controlling the movements of a mobile robot in a multiple node factory

Full	Title	Citation	Front	Review	Classification	Date	Reference			Claims	KWIC	Draw. D

☐ 7. Document ID: US 5163001 A

L25: Entry 7 of 14 File: USPT Nov 10, 1992

US-PAT-NO: 5163001
DOCUMENT-IDENTIFIER: US 5163001 A

TITLE: Interactive display for use on an automatic guided vehicle

Full	Title	Citation	Front	Review	Classification	Date	Reference			Claims	KWIC	Draw. D

☐ 8. Document ID: US 5091855 A

L25: Entry 8 of 14 File: USPT Feb 25, 1992

US-PAT-NO: 5091855
DOCUMENT-IDENTIFIER: US 5091855 A

TITLE: Operation control system for automated guide vehicles

Full	Title	Citation	Front	Review	Classification	Date	Reference			Claims	KWIC	Draw. D

☐ 9. Document ID: US 5075853 A

L25: Entry 9 of 14 File: USPT Dec 24, 1991

US-PAT-NO: 5075853
DOCUMENT-IDENTIFIER: US 5075853 A

TITLE: Replaceable vehicle control prom

Full	Title	Citation	Front	Review	Classification	Date	Reference			Claims	KWIC	Draw. D

☐ 10. Document ID: US 5023790 A

L25: Entry 10 of 14 File: USPT Jun 11, 1991

US-PAT-NO: 5023790
DOCUMENT-IDENTIFIER: US 5023790 A

TITLE: Automatic guided vehicle system

Full	Title	Citation	Front	Review	Classification	Date	Reference			Claims	KWIC	Draw. D

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs | Generate OACS

Terms	Documents
L23 and (simult$ or ((happen$ or done) with "same" with time))	14

Display Format: - Change Format

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Hit List

First Hit Clear Generate Collection Print Fwd Refs Bkwd Refs Generate OACS

Search Results - Record(s) 11 through 20 of 30 returned.

☐ 11. Document ID: US 6739635 B2
L6: Entry 11 of 30 File: USPT May 25, 2004

US-PAT-NO: 6739635
DOCUMENT-IDENTIFIER: US 6739635 B2

TITLE: Bumper device for automated guided vehicle

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☐ 12. Document ID: US 6726429 B2
L6: Entry 12 of 30 File: USPT Apr 27, 2004

US-PAT-NO: 6726429
DOCUMENT-IDENTIFIER: US 6726429 B2

TITLE: Local store for a wafer processing station

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☑ 13. Document ID: US 6445984 B1
L6: Entry 13 of 30 File: USPT Sep 3, 2002

US-PAT-NO: 6445984
DOCUMENT-IDENTIFIER: US 6445984 B1

TITLE: Steer control system for material handling vehicles

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☐ 14. Document ID: US 6345217 B1
L6: Entry 14 of 30 File: USPT Feb 5, 2002

US-PAT-NO: 6345217

DOCUMENT-IDENTIFIER: US 6345217 B1

TITLE: Automated guided vehicle (AGV) with bipolar magnet sensing

Full	Title	Citation	Front	Review	Classification	Date	Reference			Claims	KWIC	Draw. D

☐ 15. Document ID: US 5764014 A

L6: Entry 15 of 30 File: USPT Jun 9, 1998

US-PAT-NO: 5764014
DOCUMENT-IDENTIFIER: US 5764014 A
**** See image for Certificate of Correction ****

TITLE: Automated guided vehicle having ground track sensor

Full	Title	Citation	Front	Review	Classification	Date	Reference			Claims	KWIC	Draw. D

☐ 16. Document ID: US 5650703 A

L6: Entry 16 of 30 File: USPT Jul 22, 1997

US-PAT-NO: 5650703
DOCUMENT-IDENTIFIER: US 5650703 A
**** See image for Certificate of Correction ****
**** See image for Reexamination Certificate ****

TITLE: Downward compatible AGV system and methods

Full	Title	Citation	Front	Review	Classification	Date	Reference			Claims	KWIC	Draw. D

☐ 17. Document ID: US 5617320 A

L6: Entry 17 of 30 File: USPT Apr 1, 1997

US-PAT-NO: 5617320
DOCUMENT-IDENTIFIER: US 5617320 A

TITLE: Method and apparatus for an AGV inertial table having an angular rate sensor and a voltage controlled oscillator

Full	Title	Citation	Front	Review	Classification	Date	Reference			Claims	KWIC	Draw. D

☐ 18. Document ID: US 5539646 A

L6: Entry 18 of 30 File: USPT Jul 23, 1996

US-PAT-NO: 5539646

DOCUMENT-IDENTIFIER: US 5539646 A

TITLE: Method and apparatus for an AGV inertial table having an angular rate sensor and a voltage controlled oscillator

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 19. Document ID: US 5341130 A

L6: Entry 19 of 30 File: USPT Aug 23, 1994

US-PAT-NO: 5341130
DOCUMENT-IDENTIFIER: US 5341130 A

TITLE: Downward compatible AGV system and methods

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 20. Document ID: US 5281901 A

L6: Entry 20 of 30 File: USPT Jan 25, 1994

US-PAT-NO: 5281901
DOCUMENT-IDENTIFIER: US 5281901 A
**** See image for Certificate of Correction ****

TITLE: Downward compatible AGV system and methods

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs | Generate OACS

Terms	Documents
L4 and (automated adj guided adj vehicle).clm.	30

Display Format: - Change Format

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Refine Search

Search Results -

Terms	Documents
L13 and ((180/168 |701/23 |318/587).ccls.)	2

Database:

US Pre-Grant Publication Full-Text Database
US Patents Full-Text Database
US OCR Full-Text Database
EPO Abstracts Database
JPO Abstracts Database
Derwent World Patents Index
IBM Technical Disclosure Bulletins

Search: L14

Refine Search

Recall Text Clear Interrupt

Search History

DATE: Monday, January 22, 2007 **Purge Queries** Printable Copy Create Case

Set Name side by side	**Query**	**Hit Count**	**Set Name** result set
	DB=PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD; THES=ASSIGNEE; PLUR=YES; OP=OR		
L14	L13 and (701/23;180/168;318/587.ccls.)	2	L14
L13	l11 or L12	25	L13
L12	L9 and @pd<=20031014	17	L12
L11	L9 and @ad<=20031014	25	L11

L10	L9 and l5	0	L10
L9	L3 and (distance same wait$)	28	L9
L8	L3 and (automated adj guided adj vehicle).clm. and (distance with location with long$)	1	L8
L7	L4 and (automated adj guided adj vehicle).clm. and (distance with location)	7	L7
L6	L4 and (automated adj guided adj vehicle).clm.	30	L6
L5	L4 and (auto$ adj guide$ adj vehicle)	14	L5
L4	L3 and (distance and (path or way))	546	L4
L3	agvs and distanc$	641	L3
	DB=USPT; THES=ASSIGNEE; PLUR=YES; OP=OR		
L2	L1 and (distance and (path or way))	1	L2
L1	5280431.pn.	1	L1

END OF SEARCH HISTORY

L7: Entry 3 of 7 File: USPT Jun 9, 1998

US-PAT-NO: 5764014
DOCUMENT-IDENTIFIER: US 5764014 A
** See image for Certificate of Correction **

TITLE: Automated guided vehicle having ground track sensor

DATE-ISSUED: June 9, 1998

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Jakeway; Jerome J.	Belding	MI		
Mickley; Joseph G.	Kentwood	MI		
Zeitler; David W.	Byron Center	MI		
Medley; James A.	Sparta	MI		

ASSIGNEE-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY	TYPE CODE
Mannesmann Dematic Rapistan Corp.	Grand Rapids	MI			02

APPL-NO: 08/595353 [PALM]
DATE FILED: February 1, 1996

INT-CL-ISSUED: [06] G05D 1/02

INT-CL-CURRENT:

TYPE	IPC	DATE
CIPP	G05 D 1/02	20060101

US-CL-ISSUED: 318/587; 318/652, 318/618, 364/424.027
US-CL-CURRENT: 318/587; 318/618, 318/652, 701/23

FIELD-OF-CLASSIFICATION-SEARCH: 318/580, 318/587, 318/602, 318/605, 318/618, 318/648, 318/652, 318/653, 318/456, 318/457, 318/461, 318/463, 318/464, 180/6.2, 180/252, 280/1, 280/727, 364/423.098, 364/424.026, 364/424.027, 364/449.1
See application file for complete search history.

PRIOR-ART-DISCLOSED:

U.S. PATENT DOCUMENTS

Search Selected Search ALL Clear

	PAT-NO	ISSUE-DATE	PATENTEE-NAME	US-CL
☐	3845289	October 1974	French	
☐	3925641	December 1975	Kashio	
☐	4084241	April 1978	Tsumura	
☐	4139889	February 1979	Ingels	
☐	4284160	August 1981	DeLiban et al.	
☐	4309758	January 1982	Halsall et al.	
☐	4347730	September 1982	Fisher et al.	
☐	4465155	August 1984	Collins	
☐	4515221	May 1985	van der Lely	
☐	4530056	July 1985	MacKinnon et al.	
☐	4556940	December 1985	Katoo et al.	
☐	4628453	December 1986	Kamejima et al.	
☐	4698775	October 1987	Koch et al.	
☐	4723444	February 1988	Hajek	
☐	4727492	February 1988	Reeve et al.	
☐	4758959	July 1988	Thoone et al.	
☐	4779203	October 1988	McClure et al.	
☐	4800977	January 1989	Boegli et al.	
☐	4816998	March 1989	Ahlbom	
☐	4817000	March 1989	Eberhardt	
☐	4820961	April 1989	McMullin	
☐	4829442	May 1989	Kadonoff et al.	
☐	4846297	July 1989	Field et al.	
☐	4847769	July 1989	Reeve	
☐	4847774	July 1989	Tomikawa et al.	
☐	4882694	November 1989	Brubaker et al.	
☐	4887013	December 1989	Doth	
☐	4908557	March 1990	Sudare et al.	
☐	4940925	July 1990	Wand et al.	
☐	4986378	January 1991	Kasper	
☐	5029088	July 1991	Minami	
☐	5058023	October 1991	Kozikaro	
☐	5075693	December 1991	McMillan et al.	
☐	5111401	May 1992	Everett, Jr. et al.	
☐	5163001	November 1992	Luke, Jr.	
☐	5175415	December 1992	Guest	
☐	5187664	February 1993	Yardley et al.	

☐	5191528	March 1993	Yardley et al.
☐	5204814	April 1993	Noonan et al.
☐	5216605	June 1993	Yardley et al.
☐	5218542	June 1993	Endo et al.
☐	5219036	June 1993	Schwager et al.
☐	5243524	September 1993	Ishida et al.
☐	5255195	October 1993	Mochizuki et al.
☐	5281901	January 1994	Yardley et al.
☐	5334986	August 1994	Fernhout
☐	5341130	August 1994	Yardley et al.
☐	5467084	November 1995	Alofs et al.

FOREIGN PATENT DOCUMENTS

FOREIGN-PAT-NO	PUBN-DATE	COUNTRY	CLASS
0159680A2	October 1985	EP	
0193985A1	September 1986	EP	
0273976A1	July 1988	EP	
0486354A1	May 1992	EP	
0602013A2	June 1994	EP	
3003287A1	August 1980	DE	
2042217	September 1980	GB	
WO9531759	November 1995	WO	

ART-UNIT: 217

PRIMARY-EXAMINER: Ro; Bentsu

ATTY-AGENT-FIRM: Van Dyke, Gardner, Linn & Burkhart, LLP

ABSTRACT:

An automated guided vehicle includes a body, at least one driver wheel for propelling the body along a surface, at least one steered wheel for directing the body with respect to the surface and a body-based inertial navigation system. The inertial navigation system senses actual movement of the body in at least three degrees of freedom. Such sensing is accomplished notwithstanding the presence of side slippage of the vehicle. This can be embodied in an automated guided vehicle having a ground track sensor which continuously senses relative movement of the vehicle with respect to the surface being traversed in order to determine an actual velocity vector of the vehicle. The ground track sensor may physically contact the surface in order to sense the relative movement or may be a non-contact sensor. The disclosed navigation system is especially useful with tugger automated guided vehicles.

33 Claims, 10 Drawing figures

L7: Entry 3 of 7 File: USPT Jun 9, 1998

DOCUMENT-IDENTIFIER: US 5764014 A
**** See image for Certificate of Correction ****
TITLE: Automated guided vehicle having ground track sensor

Brief Summary Text (2):
This invention relates to automated guided vehicles and, in particular, to a navigation and control system for guiding an automatic guided vehicle (AGV) along a system guide path. The invention is particularly adapted for use with dead-reckoning navigation systems, but may also be utilized with systems in which the AGV follows a guide wire that is planted in the floor along the guide path. The invention finds application in material handing, such as movement of material within a factory, as well as on-road and off-road vehicles.

Brief Summary Text (3):
Automated guided vehicles have become extremely effective at movement of materials between processes in a manufacturing plant. Each of a plurality of AGVs automatically carries loads from a pickup point to a discharge point along a system guide path under the supervision of a system controller. The AGVs move along the system guide path, including choosing between branches at each branch point, while avoiding collisions with other AGVs utilizing various control techniques. Navigation of the AGV is typically either by reference to fixed guides, such as guide wires positioned in the floor along the guide path, or by dead-reckoning. Dead-reckoning systems utilize sensors within the AGV in order to monitor the heading, rate-of-change of heading, and distance travelled by the AGV along its longitudinal axis, which is controlled to coincide with the guide path. The dead-reckoning systems are advantageous because they avoid the enormous expense of placing guide wires in the floor along the entire guide path. Additionally, such dead-reckoning systems are flexible because the guide path layout may be altered by programming changes in the controls rather than requiring tearing up and repositioning of the guide wires.

Brief Summary Text (4):
Dead-reckoning systems rely upon an integration of the rate of turn of the vehicle and the distance travelled to maintain position information of the vehicle. Because such measurements tend to drift with time, it is known to supplement the dead-reckoning navigation system with a location verification system, such as markers positioned at precise locations along the system guide path. These sensors are sensed by the AGV as the AGV moves along the guide path in order to verify, and compensate if necessary, the position of the AGV.

Brief Summary Text (5):
One of the attributes of an AGV is its ability to carry enormous loads without an operator for each vehicle. In some applications, the entire load is borne by the AGV itself. In other applications, the AGV pulls, or tugs, one or more trailers which carry the load. As a loaded vehicle moves along the guide path, especially around comers, there is a tendency for the vehicle to be forced off of the guide path by the inertia of the load. Additionally, the load asserts a draft effect on the vehicle. These effects are especially troublesome, although not exclusively limited, to tugger AGVs pulling one or more trailers. This problem becomes

especially acute when the AGV traverses a floor which is uneven and has a constantly changing floor surface, such as one that has portions which vary from concrete to oily wood to steel plates, over wide expansion joints, and the like. The problem is further aggravated when the floor is covered with friction-reducing films, such as processing oils, soapy water, and the like. The slippage of an AGV may not be sensed by the vehicle primary navigation system. If the primary navigation system is a dead-reckoning system, the slippage of the vehicle may not be adequately sensed in the rate of turn sensing mechanism. Because the location verification markers are infrequently spaced along the guide path and because of the abrupt alteration of the vehicle position resulting from such slippage, the location verification system may be unable to adequately compensate for the vehicle slippage. If the primary navigation system is based upon sensing a guide wire in the floor, the presence of a pool of liquid, which may give rise to the slippage, may also interfere with adequate sensing of the guide wire.

Brief Summary Text (7):
The present invention provides an adjunct to the primary navigation system of an AGV by providing an input to the navigation and control computer of the AGV in order to more accurately determine the actual path of movement of the AGV. Such adjunct responds to slippage of the vehicle and, thereby, corrects for errors induced by such slippage and undetected by the primary navigation system. This is accomplished, according to the invention, by providing a ground track sensor which senses relative movement of the AGV with respect to the floor surface being traversed. The invention is based upon a recognition that the primary source of slippage is side-slippage of the vehicle which is not adequately detected by primary navigation systems, especially of the dead-reckoning type.

Brief Summary Text (8):
According to an aspect of the invention, an automatic guided vehicle navigation and control system includes a primary navigation system which senses a heading, or rate-of-change of heading, of an automatic guided vehicle, a ground track sensor, which senses relative movement of the automatic vehicle with respect to a surface being traversed by the vehicle, and a navigation and control computer. The navigation and control computer is responsive to the primary navigation sensing system and to the ground track sensor for determining an actual path of movement of the automatic guided vehicle. The navigation and control computer also compares the actual path of movement with an intended path of movement in order to control movement of the vehicle.

Brief Summary Text (9):
According to another aspect of the invention, a ground track sensor is provided which physically contacts the surface being traversed by the vehicle in order to sense relative movement between the AGV and the surface. The ground track sensor may include an unloaded wheel which does not bear any weight of the vehicle. The wheel preferably is a passive wheel which does not primarily steer or propel the automatic guided vehicle. Such ground-sensing wheel is rotatably mounted to the vehicle to rotate about a vertical axis and includes two precision encoders which monitor the angle of the wheel with respect to the vehicle's direction. Preferably, the wheel is mounted to the AGV with an arm that is pivoted with respect to the swiveling yoke. This allows a downward bias force to be applied to the mounting arms in order to provide firm engagement between the wheel and the floor irrespective of the irregularities in the floor.

Brief Summary Text (10):
The ground track sensor monitors movement of the AGV with respect to the floor and is capable of accurately measuring slippage laterally from the guide path from the angle and distance tavelled. This information is utilized by the navigation and control computer in order to augment the navigation information provided by the primary navigation system. According to another aspect of the invention, the primary navigation and control system includes a steered wheel odometry system

which measures the angle and distance travelled by one or more steered wheels. The navigation and control computer blends the outputs from the ground reference sensor and the steered wheel odometry system in order to compensate for any momentary interruptions in the operation of the ground-tracking sensor, such as may be experienced by a wheel encountering debris on the floor or the like. Additionally, the steered wheel odometry system may take the place of the ground track sensor when the vehicle is travelling in the reverse direction. The ground track sensor may be positioned anywhere on the underside of the vehicle or on an outrigger. A greater distance from the primary center of rotation of the vehicle provides greater resolution. However, sensor placement is possible even at the center of rotation of the vehicle, if sufficient sensor resolution is provided.

Drawing Description Text (2):
FIG. 1 is a side elevation of an automated guided vehicle (AGV) according to the invention towing a plurality of trailers;

Drawing Description Text (3):
FIG. 2 is a side elevation of the AGV in FIG. 1;

Drawing Description Text (7):
FIG. 6 is a plan view of an AGV illustrating layout and interconnection of major components of its navigation and control system;

Drawing Description Text (8):
FIG. 7 is a block diagram of the AGV navigation and control system;

Detailed Description Text (3):
Dead reckoning navigation--Navigation based upon sensing direction and distance travelled by the AGV. Examples include: (a) heading reference sensing, which measures rate of turn of the vehicle, and distance travelled, or (b) differential odometry, which measures differential rotation of spaced coaxial distance measuring encoders, and distance travelled, or (c) steered wheel odometry, which measures angle and distance travelled by one or more steered wheels; or a combination of these.

Detailed Description Text (4):
Heading reference sensor--An inertial sensor which provides a navigational computer with a measurement of an AGV's rate of turn.

Detailed Description Text (5):
primary navigation--Navigation utilizing (a) dead reckoning navigation or (b) sensing of a guide wire implanted in the floor along a desired path; or a combination of these.

Detailed Description Text (6):
Navigation computer--A computer-based system which continuously calculates the current position of the AGV based upon inputs from various guidance sensors.

Detailed Description Text (7):
System guide path--A virtual path laid out with respect to a floor. This is the intended path of travel of the AGVs and can have various branching.

Detailed Description Text (9):
Location verification system--Markers positioned at precise locations along the system guide path which are sensed by the AGV in order to verify, and compensate if necessary, the position of the AGV. This can include permanent magnets, plaques, transponders, code carriers, and the like.

Detailed Description Text (10):
Ground track sensor--A system that continuously senses actual movement of the AGV

with respect to the floor being traversed. Measures lateral travel, longitudinal travel, and/or rotation of the vehicle.

Detailed Description Text (11):
Referring now specifically to the drawings and the illustrative embodiments depicted therein, an automated guided vehicle (AGV) 10 is illustrated pulling a plurality of trailers 12 (FIG. 1). Each trailer 12 is typically loaded with materials, such as raw materials or finished components. Although the invention is illustrated with respect to such tugger AGV, its principles are applicable to AGVs in which the load is carried by the AGV per se.

Detailed Description Text (12):
AGV 12 includes a body 14 whose weight is supported by one or more rear drive wheels 16 and one or more forward steering wheels 18 (FIGS. 2-6). In the illustrated embodiment, two drive wheels 16 and one forward steering wheel 18 are utilized, although the invention is applicable to other combinations of driven and steered wheels. AGV 10 includes a local operator console 20 in order for the the vehicle to be manually operated and to be initiated into the AGV system. However, the AGV is typically under the control of a central control 21 which provides instruction to the AGV regarding its specified destination as well as the position and destination of other AGVs so that each AGV is capable of avoiding collisions with other AGVs. AGV 10 additionally includes a forward bumper 22 in order to sense impact with an object in the AGV's guide path and a hitch 24 in order to pull trailers 12.

Detailed Description Text (13):
Each AGV 10 is powered from a bank of batteries, located in a compartment 23, which supply an electric DC motor 26 associated with each drive wheel 16 through a motor control 27. AGV 10 additionally includes a ground track sensor, generally shown at 30, for continuously sensing movement of vehicle body 14 in the longitudinal direction of the vehicle as it travels along its guide path and rotation of the vehicle, as will be described in more detail below. In the illustrated embodiment, ground track sensor 30 includes a wheel 32 which is a non-load-bearing wheel with respect to vehicle body 14. Ground track sensor 30 additionally includes a support 34 for wheel 32 including a swivel joint 36 which attaches a yoke 38 for rotational movement about a vertical axis extending through a pin 40, which translates the rotational movement of the yoke to a pulley 44. Swivel 36 includes a bearing plate which is a machined ball brace. A pair of support arms 48, which are made of thick steel plate, support an axle 50 for wheel 32. Support arms 48 are pivotally mounted to yoke 38 by a yoke axle 52. Yoke axle 52 allows relative vertical movement of wheel 32 with respect to vehicle body 14. A spring 54 provides a downward bias to wheel 32 in order to maintain the wheel in constant contact with the floor. This is especially useful as the wheel runs over expansion cracks and objects on the floor so that the wheel maintains constant contact with the floor. Wheel 32 is made of a durable urethane material which both minimizes wear and provides adequate friction between the wheel surface and the floor. Additionally, this allows easy replacement of the wheel surface.

Detailed Description Text (14):
A distance-measuring encoder (DME) 56 is mounted to support arms 48 and interconnected with wheel 32 by a chain (not shown). Encoder 56 is connected electrically with a navigation and control computer 58 by a cable 60. A stationary stop 62a and a moveable finger 62b restrict rotation of yoke 38 to less than one revolution in order to protect cable 60. In the illustrated embodiment, encoder 56 provides 50 pulse-per-revolution accuracy in two quadrature channels which allows measurements of movement in both forward and reverse directions of the vehicle. In the illustrated embodiment, the encoder is used in only the forward direction of the vehicle thereby providing 100 pulse-per-revolution accuracy. As an alternative, the internal clock of the navigation and control unit may be utilized to provide interpolated pulses at 100 pulse-per-revolution in both forward and reverse

directions. Instead of using an encoder, distance may be measured by other distance measuring devices. Rotational movement of yoke 38 is transferred to a stationary precision encoder 42 by way of pulley 44 and a belt 46. Belt 46 is a cog-type timing belt in order to avoid misalignment between the pulley 44 and encoder 42. Encoder 42 is mechanically and electrically zeroed to a center position to within plus or minus 0.5 degrees of center. Encoder 42 is mounted by a bracket 64 which is adjustably mounted in order to allow tensioning of belt 46.

Detailed Description Text (15):
AGV 10 includes a vehicle navigation and steering control system 66 (FIGS. 6 and 7). System 66 includes a primary navigation system 68 which is a dead-reckoning sensing system. Primary navigation system 68 utilizes a heading reference sensor (HRS) 70, which is an inertial sensor which provides a measurement of the rate of turn of AGV 10. In the illustrated embodiment, heading reference sensor 70 is a spinning mass gyroscope marketed by Smith Industries Aerospace & Defense Systems, Inc. under Model No. 9190 A. However, other inertial sensors, such as fiber optic sensors, tuning fork sensors, and the like, may be utilized. Other dead-reckoning sensing systems could be used, such as magnetometer sensors, and the like, which sense heading of the vehicle. Primary navigation system 68 additionally includes a magnetic sensor 72 which is a location verification system. Magnetic sensor 72 senses magnetic markers which are positioned at precise locations along the system guide path in order to update the position of the AGV stored in navigation and control computer. The primary navigation system may additionally include a distance-measuring encoder (DME) 74 of a steering wheel assembly 76. Steering wheel assembly 76 additionally includes an angle encoder 78. DME 74 produces an output 80 which is supplied to navigation computer 58 that represents distance travelled by steering wheel 18. Angle encoder 78 produces an output 82 to a steering control 84 indicative of the angle of steering wheel 18 under the control of steering control 84. Ground track sensor 30 produces an output 86 to navigation and control computer 58. The output of ground track sensor 30 identifies ground track distance as well as the degree of the vehicle turn. Alternatively, distance could be measured by integration of measured velocity of the vehicle.

Detailed Description Text (17):
If slippage of AGV 10 is minimal, navigation can be done, utilizing standard dead-reckoning techniques, with primary navigation system 68 including heading rate sensor 70, distance travelled from DME 74 and turn angle from angle encoder 78. The output of heading rate sensor 70 is integrated in order to determine vehicle heading as follows:

Detailed Description Text (19):
The output of DME 74 (d.sub.s) and the output of angle encoder 78 (.theta.), along with an assumption of a fixed rotation point for the vehicle updates the location of the navigation point of the vehicle with respect to the floor. Equations 2 and 3 are incremental distances of the vehicle body 14, at point (0,0) in FIG. 8, which is the assumed vehicle velocity vector. Equations 4 and 5 integrate these components with the current (X, Y) position by rotating the distance travelled from body-based components to floor-based coordinate systems at the same time, as follows:

Detailed Description Text (20):
The invention is based upon the recognition that the assumption of minimal slippage is not always true. Although not limited to such applications, such slippage is especially present for tugger vehicles whose dynamics change drastically under loads applied to hitch 24. Varied plant floor conditions, such as wood block, steel and cement floors in the AGV, poor repair of the floor and debris, such as oil, grease, and scrap material, all add to the slippage problem. In particular, the loaded wheels, such as drive wheels 16 and steering wheel 18 are extremely susceptible to slippage. Sensors mounted on these points of the vehicle provide an opportunity for erroneous navigational information. The slippage makes the

assumption of a fixed vehicle rotation point invalid. Indeed, there are often cases where the actual rotation occurs about a point outside the vehicle, producing lateral translation rather than rotation.

Detailed Description Text (21):
This problem is cured, according to the present invention, by the addition of ground track sensor 30. Ground track sensor 30 is, in the illustrated embodiment, an unloaded, freely pivoting wheel which measures the distance travelled for the wheel and the angle the wheel has travelled with respect to the vehicle frame. Because wheel 32 does not have steering or load forces, these sources of error in sensor measurement are substantially eliminated. Additionally, its free-pivoting action allows simultaneous measurement of the vehicle rotation, movement along the longitudinal axis, and lateral translation. When this information is combined with outputs of the primary navigational system 68, both movement along the longitudinal axis and lateral translation of the vehicle can be resolved and applied to the floor position of the vehicle.

Detailed Description Text (22):
This compensation can be seen by reference to FIG. 8. This distance measured by ground track sensor 30 is transformed into body-based distances at point (0, 0) utilizing the location (L.sub.1x L.sub.1y) of ground track sensor 30 and the distance L.sub.2 of wheel 30 from pivot point 40. The effect of rotation of the vehicle, as measured by heading reference sensor 70, is then removed utilizing equations 6 and 7 as follows:

Detailed Description Text (23):
These distances are then translated to floor coordinates and summed to current plant-based X, Y positions according to equations 8 and 9 in order to arrive at an actual vehicle velocity vector, notwithstanding the presence of steer wheel slippage and/or traction wheel slippage.

Detailed Description Text (24):
It is seen by examination of equations 6-9 that the updating of the floor-based (X, Y) position of AGV 10 is a function of the heading of the vehicle, the angle of the ground track sensor, and the rotation of the ground track sensor. As such, the inputs from distance-measuring encoder 74 and the angle encoder 78 of the steering wheel assembly 76 are redundant. In one embodiment of the invention, the inputs from the steered wheel assembly are not utilized in the guidance and control of the AGV 10. Guidance of AGV 10 is a function of the readings of heading reference sensor 70 and ground track sensor 30 alone. In embodiments of the invention in which AGV 10 only travels in a forward direction, such guidance and control is sufficient. This embodiment allows ground track sensor 30 to be utilized with stops 62a, 62b which simplifies the structure of ground track sensor 30 by allowing use of a cable connection to the DME 56.

Detailed Description Text (25):
However, if AGV 10 is occasionally operated in a reverse direction, then the outputs of distance-measuring encoder 74 and angle encoder 78 of steering wheel assembly 76 are substituted for those of ground track sensor 30 when the vehicle is being driven in the reverse direction. This allows DME 56 to be utilized in a unidirectional rotation to increase resolution, as previously described. Although steering wheel 18 is a loaded and steered wheel, its performance at the rear of the vehicle, when the vehicle is being reversed, is superior to that of ground track sensor 30. In this reversing embodiment, ground track sensor 30 could be supplemented with a slip ring assembly, an inductive pickup, an optical data link, or the like, to pick up DME data while allowing yoke 38 to swivel in a full 360-degree rotation.

Detailed Description Text (26):
In an alternate embodiment of the invention, signals from encoders 42 and 56 of

ground track sensor 30 and the distance-measuring encoder 74 and angle encoder 78 of steering wheel assembly 76 are blended together even when vehicle 10 is operated in a forward direction. Such blended solution allows the navigation and steering control system to selectively ignore readings from ground track sensor 30 when such readings are invalid due to debris on the floor being traversed by wheel 32 and the like. The signals received from ground track sensor 30 and steering wheel assembly 76 are combined utilizing a Kalman filter, in a manner which would be readily apparent to those skilled in the art.

Detailed Description Text (27):
In the illustrated embodiment, updates in the position of AGV 10 are calculated at a 100 Hz update rate. The equations 6-9 are calculated with the assistance of a Model 80387 mathematic coprocessor of the type marketed by Intel Corporation or Cyrix Corporation. The present invention has been fully reduced to practice and successfully commercialized in an AGV marketed by Rapistan Demag Corporation, Grand Rapids, Mich., under Models DT-60 and DL-140. Although the invention has been illustrated with respect to a material handling AGV, it has broader application to on-road vehicle navigation, such as those utilized in commercial and personal vehicles, as well as control systems for off-road vehicles, including military vehicles, such as armored vehicles and the like.

CLAIMS:

1. An automated guided vehicle navigation and steering control system, comprising:

a primary navigation system which senses a heading or a rate-of-change of heading of an automated guided vehicle;

a ground track sensor which continuously senses relative movement of the automated guided vehicle with respect to a surface being traversed by the vehicle in order to determine an actual velocity vector of the vehicle; and

a navigation and control computer which is responsive to said primary navigation system and said ground track sensor for determining an actuated path of movement of the automated guided vehicle and for comparing said actual paths of movement with an intended path of movement in order to control movement of the vehicle.

3. The system in claim 2 wherein said ground track sensor includes a wheel in physical contact with the surface and does not carry substantially any vehicle weight and is a passive wheel which does not steer or propel the automated guided vehicle.

6. The system in claim 3 wherein said ground track sensor includes a yoke that is rotatably mounted to rotate about a vertical axis, an angle encoder which measures the radial position of said yoke with respect to said vertical axis, a wheel assembly attached to said yoke including a wheel mounted to rotate about a horizontal axis and a distance encoder measuring revolution of said wheel about said horizontal axis.

8. The system in claim 1 further including at least one driven wheel for propelling the automated guided vehicle and at least one steered wheel for directing the automated guided vehicle.

10. The system in claim 9 wherein said navigation and control computer is responsive to said steered wheel monitoring system for determining an actual path of movement of the automated guided vehicle when the vehicle is moving in a reverse direction.

15. An automated guided vehicle, comprising:

a body, at least one driver wheel for propelling said body along a surface, and at least one steered wheel for directing said body with respect to the surface;

a primary navigation system which senses a heading or a rate-of-change of heading of the body;

a distance measuring device which measures distanced travelled by said body in a longitudinal direction;

a ground track sensor which is independent of said wheels and which continuously monitors movement of said body with respect to the surface at least in a lateral direction; and

a navigation and control computer which is responsive to said primary navigation system, to said distance measuring device and to said ground track sensor for determining an actual path of movement of said body and for controlling said steering wheel in order to direct said body along an ideal path of movement.

17. The vehicle in claim 16 wherein said ground track sensor includes a wheel in physical contact with the surface and does not carry substantially any vehicle weight and is a passive wheel which does not steer or propel the automated guided vehicle.

19. The vehicle in claim 17 wherein said ground track sensor includes a yoke that is rotatably mounted to rotate about a vertical axis, an angle encoder which measures the radial position of said yoke with respect to said vertical axis, a wheel assembly attached to said yoke and including a wheel mounted to rotate about a horizontal axis, and a distance encoder measuring revolution of said wheel about said horizontal axis.

21. The vehicle in claim 20 wherein said navigation and control computer is responsive to said steered wheel monitoring system for determining an actual path of movement of the automated guided vehicle when the vehicle is moving in a reverse direction.

25. An automated guided vehicle comprising:

a body, at least one driver wheel for propelling said body along a floor, at least one steered wheel for directing said body with resect to the floor, and a steered wheel monitoring system which monitors steering angle of said at least one steered wheel;

an inertial navigation sensor which senses rate-of-change of heading of said body;

a ground track sensor which monitors a ground velocity vector with respect to said body independent of said wheels; and

a navigation and control computer which is responsive to said inertial navigation sensor and to said steered wheel monitoring system and said ground track sensor for determining an actual path of movement of said body and for controlling said steering wheel in order to direct said body along an ideal path of movement.

26. The vehicle in claim 25 wherein said navigation and control computer determines an actual path of movement of said body in response to said ground track sensor when the vehicle is moving in a forward direction.

27. The vehicle in claim 25 wherein said navigation and control computer determines an actual path of movement of said body as a blend of said ground track sensor and said steered wheel monitoring system.

28. The vehicle in claim 25 wherein said navigation and control computer determines an actual path of movement of said body in response to said steered wheel monitoring system when the vehicle is moving in a reverse direction.

29. An automated guided vehicle comprising:

a body, at least one driver wheel for propelling said body along a floor, and at least one steered wheel for directing said body with respect to the floor; and

a body-based inertial navigation system which senses actual movement of said body in at least three degrees of freedom irrespective of side slippage of the vehicle.

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TITLE: Automated guided vehicle (AGV) with bipolar magnet sensing

DATE-ISSUED: February 5, 2002

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FIELD-OF-CLASSIFICATION-SEARCH: 701/23, 318/580, 318/587
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U.S. PATENT DOCUMENTS

Search Selected   Search ALL   Clear

	PAT-NO	ISSUE-DATE	PATENTEE-NAME	US-CL
☐	4908557	March 1990	Sudare et al.	318/587
☐	5189612	February 1993	Lemercier et al.	701/23

☐	5191528	March 1993	Yardley et al.	701/23
☐	5216605	June 1993	Yardley et al.	701/23
☐	5434781	July 1995	Alofs et al.	701/23
☐	5853846	December 1998	Clark et al.	701/23
☐	5883587	March 1999	Ikemoto	340/988
☐	6035248	March 2000	Nagai et al.	701/23

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ABSTRACT:

An automated guided vehicle system and method includes providing at least one automated-guided vehicle (AGV) and a pathway for the AGV. A sensor assembly on the AGV senses magnet assemblies on the pathway as the AGV is transported over that magnet assembly. A navigation and guidance system determines the location of the maximum magnitude of the magnetic field by mathematically fitting a curve to the magnitude of portions of the magnetic field sensed by said magnetic sensors and determines a maximum value of the curve. At least some of the said magnet assemblies each produce a bipolar magnetic field extending generally transverse to the pathway and the sensor assembly produces an output indicative of magnitude and polarity of respective portions of the bipolar magnetic field. The navigation and guidance system determines a location of maximum magnitude of the opposite polarities of the bipolar magnetic field and a correction factor. The correction factor corrects for offset of the maximum magnitudes of the field from a predetermined location on that magnet assembly including correcting for any skew of the bipolar magnetic field with respect to said pathway.

27 Claims, 12 Drawing figures

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DOCUMENT-IDENTIFIER: US 6345217 B1
TITLE: Automated guided vehicle (AGV) with bipolar magnet sensing

Abstract Text (1):
An automated guided vehicle system and method includes providing at least one automated-guided vehicle (AGV) and a pathway for the AGV. A sensor assembly on the AGV senses magnet assemblies on the pathway as the AGV is transported over that magnet assembly. A navigation and guidance system determines the location of the maximum magnitude of the magnetic field by mathematically fitting a curve to the magnitude of portions of the magnetic field sensed by said magnetic sensors and determines a maximum value of the curve. At least some of the said magnet assemblies each produce a bipolar magnetic field extending generally transverse to the pathway and the sensor assembly produces an output indicative of magnitude and polarity of respective portions of the bipolar magnetic field. The navigation and guidance system determines a location of maximum magnitude of the opposite polarities of the bipolar magnetic field and a correction factor. The correction factor corrects for offset of the maximum magnitudes of the field from a predetermined location on that magnet assembly including correcting for any skew of the bipolar magnetic field with respect to said pathway.

Brief Summary Text (2):
This invention relates generally to automated-guided vehicle (AGV) systems and, in particular, to navigation and control systems for guiding an automated-guided vehicle along a system guide path. The invention finds application in material handling, such as movement of material within a factory, as well as on-road and off-road vehicles.

Brief Summary Text (3):
Automated-guided vehicles have become extremely effective at movement of materials between processes in a manufacturing plant. Each of a plurality of AGVs automatically carries a load from a pickup point to a discharge point along a system guide path. Navigation of the AGV is typically either by reference to fixed guides, such as guide wires positioned in the floor along the guide path, or by dead-reckoning. Dead-reckoning systems utilize sensors within the AGV in order to monitor the heading, rate-of-change of heading and distance traveled by the AGV along its longitudinal axis which is controlled to coincide with the guide path. The dead-reckoning systems are advantageous because they avoid the enormous expense of placing guide wires in the floor along the entire guide path. Additionally, such dead-reckoning systems are flexible because the guide path layout may be altered by programming changes in the controls rather than requiring tearing and repositioning of the guide wires.

Brief Summary Text (4):
Dead-reckoning systems rely upon an integration of the rate of turn of the vehicle and the distance traveled to maintain position information of the vehicle. Because such measurements tend to drift with time, it is known to supplement the dead-reckoning navigation system with a location verification system, such as markers positioned at known locations along the system guide path. These markers are sensed by a sensor assembly on the AGV as the AGV moves along the guide path in order to

verify and compensate, if necessary, the position of the AGV.

Brief Summary Text (5):
One type of marker is a cylindrical magnet positioned in the floor which is sensed by a sensor assembly made up of a series of magnetic sensors, such as Hall-effect sensors, laterally spaced along the bottom of the AGV body. Every time the vehicle passes over a magnet, a location of the body with respect to the magnet is determined from the outputs of the magnetic sensors and used to update the position information of the vehicle. An example of such a system is disclosed in U.S. Pat. No. 4,772,832 to Okazaki et al. Such a system is also utilized in automated-guided vehicle systems marketed by Applicants' assignee, Rapistan Systems of Grand Rapids, Mich. The Rapistan Systems AGV is marketed under various model numbers, such as Model No. DT-100,and is embodied in various forms. These include tuggers and unit load carriers, to name a few. The sensor assembly employed in the Rapistan Systems AGV includes a series of magnetic sensors in the form of Hall-effect sensors spaced approximately 1 inch apart. The position of the vehicle with respect to a magnet is determined by identifying the three sensors having the highest output and interpolating the values of the outputs to identify the maximum magnetic field intensity sensed by the sensor assembly. While the theoretical accuracy of such system is within 1/4 inch, there is a tendency for the existing algorithm solution to group, or settle, at the integer distance values, i.e., every inch, which corresponds to the locations of the magnetic sensors. This tendency to settle on the integers reduces the accuracy of the detection of the magnet.

Brief Summary Text (7):
For example, each vehicle must be initialized into the system at an initialization station. An initialization station consists of two spaced apart magnets at a unique distance. The initialization station provides initial position and bearing information to the vehicle dead-reckoning system to allow the vehicle to travel along the guide path. Because it is necessary that each initialization station be uniquely identified to the vehicle, various schemes have been proposed to provide that information to the vehicle. One scheme is to vary the spacing between the magnets at the initialization station. For example, the two magnets may be spaced apart at unique separation distances which, for example, may be between 4 feet and 15 feet. In order to accommodate tolerances, the unique separation distances are provided in steps, such as 6-inch steps, in order to ensure that one initialization station is not mistaken for another. The requirement that the separation of the magnets be uniquely assigned in no finer than 6-inch increments and between fixed limits, such as 4 feet and 15 feet, severely limits the number of initialization stations in the system. In this example, no more than 22 stations are possible. This, in turn, limits the flexibility in constructing very large systems.

Brief Summary Text (9):
Proposals have been made for magnetic position update systems that present magnetic fields of opposite polarity, generated by the north and south poles of the magnet at the surface of the pathway, for sensing by the sensor assembly. One such system is disclosed in U.S. Pat. No. 4,908,557 issued to Sudare et al. In Sudare et al., a position of the vehicle with respect to each magnet is determined by repeatedly scanning the magnetic sensors as the vehicle passes over the magnet in order to determine a region pair which includes two regions of equal level of magnetic magnitude. A shortest distance is obtained with respect to the two regions and a center position of the two regions is selected on the basis of the shortest distance. This is supposed to represent a null point between the opposite polarity fields. While the Sudare et al. system provides the ability to determine the direction that the vehicle passes over each magnet, it is not without its difficulties. The Sudare et al. system has precision of measurement on the order of magnitude of center-to-center spacing of the Hall-effect sensors.

Brief Summary Text (10):
One of the difficulties in sensing a position of an AGV body with respect to a

magnet assembly producing a bipolar magnetic field is that the maximum strength of the associated polarity of the field does not tend to correspond with any physical place on the magnet, such as the north face or south face. In order to be able to determine a relative position between an AGV body and a magnet assembly, a predetermined position on the magnet assembly must be selected for sensing. Because the maximum field strength for a polarity does not necessarily correspond with a location on the magnet generating the bipolar magnetic field with respect to the surface the vehicle travels, it becomes difficult to locate the magnet assembly in the coordinates of the factory floor. Another difficulty with sensing the bipolar magnetic field is that, unlike a unipolar magnetic field, the axis passing through the north and south poles can become skewed with respect to the guide path unless expensive placement techniques are used. Such skewing could significantly affect the ability to establish a unique position of the magnet assembly with respect to the vehicle body.

Brief Summary Text (12):
The present invention provides an automated-guided vehicle system in which position updates are obtained from magnets generating bipolar magnetic signals in which accuracy of the relative position between the vehicle and the magnet assembly is significantly better than that achieved by the prior art. By utilizing magnet assemblies capable of producing bipolar magnetic signals, the present invention provides information on the direction being traveled by the vehicle as it traverses a magnet assembly. This may be useful in providing an improved initialization station as well as other enhanced features in an AGV system.

Brief Summary Text (17):
By determining a maximum value of the curve corresponding to the substantially maximum magnitude of the magnetic field, a database can be established of readings from multiple passes across each of the magnet assemblies. In this manner, diagnosis of the condition of each magnet assembly can be made and maintained in order to determine when maintenance is required on any particular magnet assembly or on an automated-guided vehicle. Furthermore, determining of a maximum value of a curve mathematically fitted to the intensity of portions of magnetic fields sensed by the magnetic sensors provides an exceptionally accurate value of maximum magnitude of the magnetic field sensed by the sensor assembly. In this manner, a more accurate determination of a position of the AGV body with respect to the magnet assembly as the sensor assembly passes over that magnet assembly can be made, thereby improving the overall accuracy of the guidance of the AGVs.

Brief Summary Text (19):
By providing the ability to accurately determine the location of the AGV body with respect to a magnet assembly producing a bipolar magnetic field transversed to the pathway, the present invention, for the first time, facilitates the use of magnet assemblies producing such bipolar magnetic fields without detriment to the position updating function. This is accomplished by determining a correction factor. The correction factor allows a precise determination of a location of the vehicle with respect to a location, such as the north face, or south face of the magnet assembly. This is in contrast to prior art magnet assemblies positioned with their bipolar magnetic field transverse the pathway, wherein the vehicle attempts to identify the null between the opposite polarity fields. Furthermore, the correction factor corrects for any skew of the bipolar magnetic field thereby reducing the necessity for accurately positioning the magnets with respect to the pathway.

Brief Summary Text (21):
Furthermore, the use of a magnet assembly producing a bipolar magnetic field transverse the pathway allows the magnet assembly to function as a signaling device signaling information to the vehicle. For example, one pole of the bipolar magnetic field may be an electromagnet that is controllable as part of an overall control scheme. By selectively activating that pole, the magnet assembly may perform the same function presently being performed by beacon assemblies. For example, the

selective activation of one pole may provide an indication to the vehicle that it is supposed to take a particular path to a junction point. This is especially useful for certain types of systems which do not provide wireless destination codes to the vehicle. The present invention provides the ability for such system to locally indicate to the vehicle, for example, the beckoning of that vehicle by an operator or the like.

Drawing Description Text (3):
FIG. 2 is a bottom plan view of an AGV illustrating layout and interconnection of major components of its navigation and guidance system;

Drawing Description Text (10):
FIG. 9 is a diagram illustrating correction factor required to compensate for skew of the magnet assembly with respect to the guide path;

Detailed Description Text (2):
Referring now specifically to the drawings, and the illustrative embodiments depicted therein, an automated-guided vehicle system 10 includes one or more automated-guided vehicles 12 and a pathway 13 for the automatic-guided vehicle(s) (FIGS. 1-4). Each AGV 12 includes a body 14 whose weight is supported by wheels including one or more rear drive wheels 16 and one or more forward steering wheels 18. AGV 12 is generally of the type described in commonly assigned U.S. Pat. No. 5,764,014 issued to Jakeway et al., the disclosure of which is hereby incorporated herein by reference. AGV 12 is described in detail in the '014 patent and will not be repeated herein. Suffice it to say, AGV 12 includes a local operator console 20 in order for the vehicle to be manually operated and to be initialized into the pathway 13. The AGV may also be provided with destination codes, such as via an RF link 32, as well as information of the position of other AGVs in the system so that each AGV is capable of avoiding collisions with other AGVs. AGV 12 additionally includes a forward bumper 22 in order to sense impact with an object in the AGV's guide path and, optionally, a hitch 24 in order to pull trailers. Each AGV 12 is powered from a bank of batteries, located in a compartment 23, which supplies an electric DC motor 26 associated with each drive wheel 16 through a motor control 27. AGV 12 may additionally include a ground track sensor generally shown at 30 for continuously sensing in conjunction with the gyro the movement of the body 14 in a lateral and longitudinal direction of the vehicle as it travels along its guide path.

Detailed Description Text (3):
AGV 12 additionally includes a navigation and guidance system 66 including a Heading Reference Sensor (HRS) 70, a sensor assembly 72, for sensing magnet assemblies 28 in order to update the position of the AGV stored in navigation and guidance system 66. The primary navigation system may additionally include a Distance Measuring Encoder (DME) of a steering wheel 76. Steering wheel assembly 76 may additionally include an angle encoder 78, which produces an output 82 to a steering control 84 indicative of the angle of steering wheel 18 under the control of steering control 84. Navigation and guidance system 66 additionally includes a navigation computer 58 and a vehicle computer 90. Navigation computer 58 receives inputs from ground track sensor 30, a HRS 70, a DME 74 and a sensor assembly 72.

Detailed Description Text (4):
Pathway 13 is defined by a surface 34, such as a shop floor, road surface, or the like, and a virtual guide path 36, stored in memory in each AGV 12 which defines a path along surface 34. Each virtual guide path 36 includes one or more magnet assemblies 28 spaced along the virtual guide path in order to update the position of the AGV as it travels along the virtual guide path as is understood by those skilled in the art. The pathway 32 may additionally include one or more stations 38 which provide destinations for AGVs 12. A Constant System Monitor (CSM) 40 may additionally be provided in order to re-transmit blocking codes between AGVs 12 as well as to transmit destination codes, each identifying a station 38, to the

vehicles 12. On very simple systems, the CSM 40 may provide only transmission of blocking codes between vehicles or may be eliminated altogether.

Detailed Description Text (5):
Pathway 13 may additionally include one or more initialization stations 42 which are uniquely identified locations to introduce AGVs 12 into pathway 32. This is necessary in order to coordinate the information in navigation and guidance system 66 with the location and direction of movement of the AGV 12. Each initialization station includes two magnet assemblies 28 which are separated a distance D. Traditionally, distance D is varied from one initialization station to the next in order to uniquely identify each initialization station. By way of example, in a conventional automated-guided vehicle system, the distance D may vary from 4 feet to 15 feet in 6-inch increments. Such conventional system would be limited to 22 initialization stations. Additionally, initialization station 42 may include an indicia 44 in order to indicate to a vehicle operator the direction that the vehicle is to traverse the magnet assemblies 28 making up the initialization station 42. As will be set forth in more detail below, the present invention provides a unique ability to increase the number of initialization stations 42 by uniquely identifying magnet assemblies 28 as having each one of two possible orientations with respect to guide path 36. This provides the two magnet assemblies of each induction station to have 8 unique combinations of orientations. This may increase the number of possible initialization stations by a factor of 4. Alternatively, the orientations of magnet assemblies 28 may be arranged in order to identify the direction that an AGV is to be inducted to the pathway 32. For example, if the protocol is that the magnet assemblies 28 at each initialization station are to have a particular orientation, the AGV navigation and guidance system will be able to determine if it is being operated to the initialization station in the wrong direction if the reading of the magnet assemblies indicates that the magnet assemblies have a different orientation than that expected.

Detailed Description Text (6):
The ability of AGV 12 to determine both the position of its body 14 with respect to a magnet assembly 28 and, additionally, a direction that a body 14 is traversing the magnet assembly 28 is a result of at least some of the magnet assemblies 28 producing a bipolar magnetic field by that magnet assembly at surface 34 with respect to movement of AGV 12 along virtual guide path 36 (FIG. 4). The bipolar magnetic field is generated by exposing both a magnetic north pole 46 and a magnetic south pole 48 at surface 34. This may be accompanied by positioning an individual magnet 50 with its magnetic poles 46 and 48 at surface 34. Alternatively, a magnet assembly 28' may be provided having separate magnets 50a and 50b positioned adjacent each other with one magnet's north pole at surface 34 and the other magnet's south pole at surface 34. Alternatively, a magnet assembly 28" may be provided having one or more poles 50c supplied by an electromagnet. Magnet assembly 28" may be used as a signaling device to signal to AGV 12 the state of an input 80, as will be set forth in detail below. Controllable magnetic poles 50c may be combined with a permanent magnetic pole 50d or with another electromagnetic pole. Either way, the magnetic field produced by magnet assembly 28, 28' is bipolar as sensed above the magnet assembly by an AGV 12 traversing surface 34 along virtual guide paths 36 as will be set forth in more detail below. The magnetic field produced by magnet assembly 28" may be unipolar or bipolar depending upon the state of input 80.

Detailed Description Text (7):
Sensor assembly 72 includes a plurality of magnetic sensors 52 spaced apart from each other, typically a fixed distance, and supported by a support 54 which, in the illustrated embodiment, is a circuit board (FIGS. 5 and 6). Support 54 is mounted within a housing (not shown) and positioned at the underside of body 14, as best illustrated in FIG. 2. Sensor assembly 72 is positioned on body 14 such that magnetic sensors 52 are spaced apart in a direction transverse the direction of movement of AGV 12 along pathway 13. In the illustrated embodiment, magnetic

sensors 52 are Hall-effect sensors but other magneto-responsive devices may be used. Hall-effect sensors, advantageously, produce an output which varies proportionately to the intensity of the magnetic field sensed by sensor assembly 72. Additionally, each magnetic sensor 52 is biased in a manner that it responds to the polarity of the magnet field to which it is exposed. Each magnetic sensor 52 is connected in a sensing circuit 56 which includes, for each magnetic sensor, an operational amplifier 60 which receives a bias input 62 and amplifies the output of the associated magnetic sensor 52 in a range established by the level of its bias input 62. The outputs 64 of the operational amplifiers are supplied to a digital processing system 68 which produces an output 69 supplied to navigation computer 58. Digital processor 68, which preferably includes a micro-computer, multiplexes outputs 64 and converts the analog signals to digital signals which are converted to a serial data stream output at 69. The serial data stream represents normalized levels of magnitude and polarity sensed by each magnetic sensor 52.

Detailed Description Text (15):
By mathematically fitting a curve to the data points, a more precise maximum, or minimum, peak of the magnetic field can be identified. This allows a more precise determination of the relative position of body 14 with respect to a magnet assembly 28 as the AGV passes over the magnet assembly. Furthermore, the present invention provides the ability to determine the magnitude of the maximum magnetic field sensed by sensor assembly 72. This magnetic intensity magnitude may be stored in a diagnostic computer and compared with previously read values of magnitude every time an AGV 12 passes over that particular magnet assembly. In this manner, the performance of each magnet assembly can be monitored and utilized to determine, for example, a degradation in performance of that magnet assembly. The present invention could also be used to monitor performance of an AGV 12 in its ability to sense the magnetic field of each magnet assembly 28. As will be apparent to those skilled in the art, a comparison of the magnitude of each magnet assembly taken with each AGV in the system would readily provide the ability to determine malfunctions of either a magnet assembly or an AGV.

Detailed Description Text (19):
The angle of incidence I will increase as the relative locations of the max and min values, as sensed by the AGV, decrease and vice versa. In particular, if magnet assembly 28 is positioned with its north and south poles perpendicular to guide path 36, the locations of the min and max values will be greater than for any other orientation of the magnet with respect to the guide path.

Detailed Description Text (20):
The relationship between the orientation of the poles of magnet assembly 28 and the guide path can best be illustrated by reference to FIGS. 9 and 10. FIG. 9 is a polar coordinate plot illustrating the relationship between a calculated value of a location on vehicle body 14 with respect to the magnet assembly 28 utilizing equation 2 versus the actual location of the body with respect to the magnet assembly. This is illustrated for various orientations of the magnet assembly with respect to the guide path. The guide path is illustrated as the horizontal axis passing through the 0, 180.degree. angles of the plot. The optimal orientation of magnet assembly 28 with respect to guide path 36 would be with a line passing through the north and south poles oriented along the vertical axis extending through the 90, 270.degree. angles. As the magnet assembly is skewed one way or the other with respect to guide path 36, the location of the predetermined position on the magnet assembly, which is considered in the illustrated embodiment to be the north face (N-face), changes with respect to the guide path (actual N-face location or "Actual"). The location of the predetermined position (N-face) with respect to the vehicle that is calculated utilizing Equation 2 ("Calculated" N-face position) produces a curve that also changes as the magnet assembly is skewed with respect to the guide path. When values of the "Calculated" and "Actual" values are compared, as illustrated in FIG. 10, a "correction" curve can be determined. As is readily apparent from FIG. 10, the "correction" curve is linear and may be defined by a

specific equation as set forth in FIG. 10. Because the correction curve is linear, the relationship between the max and min peaks determined from C1 and C2 may be readily converted to a precise relationship between the predetermined position on the magnet, such as the north face, for example, and the vehicle body. It should be understood that other portions of the magnet, such as the south face, could also be utilized as the predetermined location on the magnet assembly.

Detailed Description Text (21):
A method 100 for determining a relationship between AGV body 14 and a predetermined position of magnet assembly 28 begins at 102 by obtaining and normalizing data at 104 as sensor assembly 72 passes over a magnet assembly (FIG. 11). Data is normalized utilizing base line data obtained during calibration of sensor assembly 72. In the illustrated embodiment, sensor assembly 72 is calibrated in response to a manual calibration command, such as would be given following maintenance on the particular AGV, but other calibration criteria may be used. The data is normalized by applying particular values to bias input 62 for each of the magnetic sensors 52. After the data is normalized, rough minimum, and maximum, readings for respective polarities are obtained at 106 and data points on both sides of the min and max values are utilized at 108 in order to fit a curve, such as a quadratic curve, to the data points for the extremes of both opposite polarities of the magnetic data. Positions of the max and min peaks of the curves are obtained at 110 using Equations 1 and 2, and the relationship between the max and min peaks, expressed as a percentage, is obtained at 112 utilizing Equation 2. This relationship is converted, such as by applying to a look-up table, to obtain an angle of incidence of magnet assembly 28 with respect to the guide path at 114. The angle of incidence is converted to a correction factor at 116, such as by applying the angle of incidence to another look-up table. Alternatively, mathematical algorithms could be utilized at 114 and 116 to perform the conversion, as would be apparent to the skilled artisan. At 118, the values of the correction factor obtained at 116 and the locations of the max or min peak are combined. The method ends at 120. In order to establish pathway 13, it is necessary that an absolute point be established on each magnet assembly which may be utilized to survey the magnet in order to establish the precise position of the magnet with respect to the pathway. If the absolute point is assigned to the north pole face (and the north pole face produces the maximum peak in the magnetic data), then the correction factor is combined with the maximum peak in order to identify the position of the absolute point of the magnet assembly with respect to sensor assembly 72 and, hence, vehicle body 14. If the south pole face is utilized as the absolute point to survey off of (and the south pole produces the minimum peak in the magnet data), then the correction factor is combined with the minimum peak in order to establish the position of the magnet assembly with respect to the vehicle body. Of course, the correction factor would be different dependent upon whether the absolute point, or predetermined position, is the north pole face or the south pole face or some point in between.

Detailed Description Text (22):
FIG. 12 illustrates an application of the invention to an AGV system in which only one of the magnetic poles is sensed at a time by sensor assembly 72, such as when sensing a magnet with only one pole at the pathway surface. Such a sensing scheme is utilized in the AGV systems marketed by Rapistan Systems of Grand Rapids, Mich. As can be seen by reference to FIG. 12, a curve C is fit to the data points at the maximum value of the sensed magnetic field. Equations 1 and 2 are utilized to identify a maximum point of the curve. From there, the location of the relative position of AGV body 14 and the magnet assembly 28 can be determined. Although the alternative embodiment illustrated in FIG. 12 does not provide directional information of the AGV traveling with respect to the magnet assembly, it provides a more accurate determination of the relationship between the AGV body and the magnet assembly than has heretofore been possible. Furthermore, unlike previous systems, the present invention does not have a tendency to settle on integer values of position along the sensor assembly.

Detailed Description Text (23):
Thus, the present invention provides the ability to provide an accurate measurement of the relative position between the vehicle body and a magnet assembly, even if the magnet assembly is oriented with both its magnetic poles at the pathway surface such that a bipolar magnet field is generated. This provides the ability to determine the direction that the AGV is passing over the magnet assembly. By providing this ability, the present invention makes possible an enhanced initialization station function both in terms of facilitating an increase in the number of initialization stations that may be used in very large AGV systems and in providing the ability to protect against initialization of the vehicle traveling in the wrong direction across the magnet assemblies.

Detailed Description Text (24):
The present invention also provides the ability of the magnet assemblies to function as beacons or indicators to provide, without the necessity of separate transmitters and receivers, the ability to signal to the AGV information as the AGV traverses the magnet assembly. This may be accomplished by making one or both of the poles from electromagnets thereby allowing a particular pole to be switched ON or OFF. Thus, for example, if an operator wishes to summons a vehicle to its station to pick up a load, the operator could activate a switch that, in turn, activates a south pole of a magnet assembly close to that station. As the vehicle traverses the magnet assembly in order to update its position, the vehicle would detect the north pole, which it, in the illustrated example, would be utilized to update its position and would also detect a south pole magnetic field. The vehicle would then be programmed to divert to a spur track and thereby fulfill the operator's request. Other examples would suggest themselves to the skilled artisan. For example, if a bridge or door, or the like, is capable of assuming a position in which the AGV can pass and a position in which the AGV cannot pass, information about the position of the bridge or door may be supplied to a magnet assembly ahead of the location. Dependent upon the position of the obstacle, an electromagnet may be actuated or not actuated in the magnet assembly and the vehicle interprets the state of the electromagnet as the vehicle passes over the magnet assembly.

CLAIMS:

1. An automated-guided vehicle system, comprising:

at least one automated-guided vehicle including a body, a plurality of wheels for transporting said body across a surface, a navigation and guidance system and a sensor assembly;

a pathway for said at least one automated-guided vehicle defined by a surface and including a plurality of magnet assemblies positioned along said surface and generating magnetic fields;

said sensor assembly made up of a plurality of magnetic sensors arranged generally transverse to said pathway, said sensor assembly positioned at said body for sensing the magnetic field of each said magnet assembly as said body is transported over that magnet assembly by said wheels, said sensor assembly producing an output indicative of intensity of respective portions of the magnetic field sensed by said magnetic sensors;

said navigation and guidance system receiving said output from said sensor assembly and determining from said output a location of the substantially maximum magnitude of the magnetic field sensed by said sensor assembly at each said magnet assembly, wherein said navigation and guidance system determines a position of said body with respect to a magnet assembly as said sensor assembly passes over that magnet assembly from the substantially maximum magnitude of the magnetic field; and

wherein said navigation and guidance system determines the location of the

substantially maximum magnitude of the magnetic field by mathematically fitting a curve to the intensity of portions of the magnetic field sensed by said magnetic sensors and evaluating at least one feature of the fitted curve.

2. An automated-guided vehicle system, comprising:

at least one automated-guided vehicle including a body, a plurality of wheels for transporting said body across a surface, a navigation and guidance system and a sensor assembly;

a pathway for said at least one automated-guided vehicle defined by a surface and including a plurality of magnet assemblies positioned along said surface and generating magnetic fields;

said sensor assembly made up of a plurality of magnetic sensors arranged generally transverse to said pathway, said sensor assembly positioned at said body for sensing the magnetic field of each said magnet assembly as said body is transported over that magnet assembly by said wheels, said sensor assembly producing an output indicative of intensity of respective portions of the magnetic field sensed by said magnetic sensors;

said navigation and guidance system receiving said output from said sensor assembly and determining from said output a location of the substantially maximum magnitude of the magnetic field sensed by said sensor assembly at each said magnet assembly, wherein said navigation and guidance system determines a position of said body with respect to a magnet assembly as said sensor assembly passes over that magnet assembly from the substantially maximum magnitude of the magnetic field; and

wherein said navigation and guidance system determines the location of the substantially maximum magnitude of the magnetic field by mathematically fitting a curve to the intensity of portions of the magnetic field sensed by said magnetic sensors, wherein said mathematically fitting a curve includes providing a quadratic fit to at least some of the portions of the magnetic field sensed by said magnetic sensors.

3. An automated-guided vehicle system, comprising:

at least one automated-guided vehicle including a body, a plurality of wheels for transporting said body across a surface, a navigation and guidance system and a sensor assembly;

a pathway for said at least one automated-guided vehicle defined by a surface and including a plurality of magnet assemblies positioned along said surface and generating magnetic fields;

said sensor assembly made up of a plurality of magnetic sensors arranged generally transverse to said pathway, said sensor assembly positioned at said body for sensing the magnetic field of each said magnet assembly as said body is transported over that magnet assembly by said wheels, said sensor assembly producing an output indicative of intensity of respective portions of the magnetic field sensed by said magnetic sensors;

said navigation and guidance system receiving said output from said sensor assembly and determining from said output a location of the substantially maximum magnitude of the magnetic field sensed by said sensor assembly at each said magnet assembly, wherein said navigation and guidance system determines a position of said body with respect to a magnet assembly as said sensor assembly passes over that magnet assembly from the substantially maximum magnitude of the magnetic field; and

wherein said navigation and guidance system determines the location of the

substantially maximum magnitude of the magnetic field by mathematically fitting a curve to the intensity of portions of the magnetic field sensed by said magnetic sensors, including determining at least one value of the curve and storing the at least one value of the curve for said magnet assemblies, wherein said at least one value is chosen from a maximum value of the curve and a minimum value of the curve.

4. The automated-guided vehicle system in claim 3 including comparing multiple readings of the at least one value of the curve at the same magnet assembly in order to diagnose the condition of that magnet assembly.

5. The automated-guided vehicle system in claim 4 wherein the multiple readings of the at least one value of the curve are made for the same magnet by multiple passes by the same vehicle over that magnet assembly.

6. The automated-guided vehicle system in claim 4 wherein said at least one automated-guided vehicle includes a plurality of automated-guided vehicles and wherein the multiple readings of the at least one value of the curve are made for the same magnet by multiple vehicles passing over that magnet assembly.

7. An automated-guided vehicle system, comprising:

at least one automated-guided vehicle including a body, a plurality of wheels for transporting said body across a surface, a navigation and guidance system and a sensor assembly;

a pathway for said at least one automated-guided vehicle defined by a surface and including a plurality of magnet assemblies positioned along said surface and generating magnetic fields;

said sensor assembly made up of a plurality of magnetic sensors arranged generally transverse to said pathway, said sensor assembly positioned at said body for sensing the magnetic field of each said magnet assembly as said body is transported over that magnet assembly by said wheels, said sensor assembly producing an output indicative of intensity of respective portions of the magnetic field sensed by said magnetic sensors;

said navigation and guidance system receiving said output from said sensor assembly and determining from said output a location of the substantially maximum magnitude of the magnetic field sensed by said sensor assembly at each said magnet assembly, wherein said navigation and guidance system determines a position of said body with respect to a magnet assembly as said sensor assembly passes over that magnet assembly from the substantially maximum magnitude of the magnetic field; and

wherein said navigation and guidance system determines the location of the substantially maximum magnitude of the magnetic field by mathematically fitting a curve to the intensity of portions of the magnetic field sensed by said magnetic sensors, wherein at least some of said magnet assemblies each produce a bipolar magnetic field at said surface extending generally transverse to said pathway with respect to movement of said at least one automated-guided vehicle along said pathway and wherein said navigation and guidance system assembly determines a correction factor correcting for offset between the maximum magnitude of the magnetic field and a predetermined location of that magnet assembly including correcting for any skew of the bipolar magnetic field with respect to said pathway.

8. The automated-guided vehicle system in claim 7 wherein said navigation and guidance system determines from said output locations of maximum magnitudes of both opposite polarities of the bipolar magnetic field sensed by said sensor assembly and wherein said navigation and guidance system determines said correction factor

from the locations of maximum magnitudes of both opposite polarities of the bipolar magnetic field.

9. The automated-guided vehicle system in claim 7 wherein said at least one magnet for at least some of said magnet assemblies is a permanent magnet.

10. The automated-guided vehicle system in claim 9 wherein said pair of opposite magnetic poles for said at least some of said magnet assemblies is defined by opposite magnetic poles of one magnet.

11. The automated-guided vehicle system in claim 9 wherein said pair of opposite magnetic poles for said at least some of said magnet assemblies is defined by opposite magnetic poles of two permanent magnets.

12. The automated-guided vehicle system in claim 7 wherein at least one of said opposite magnetic poles for at least some of said magnet assemblies is defined by an electromagnet.

13. The automated-guided vehicle system in claim 12 wherein said electromagnet is selectively actuated to provide a signal to said at least one automated-guided vehicle at said sensor assembly as it passes over the associated magnet assembly.

14. An automated-guided vehicle system, comprising:

at least one automated-guided vehicle including a body, a plurality of wheels for transporting said body across a surface, a navigation and guidance system and a sensor assembly;

a pathway for said at least one automated-guided vehicle defined by a surface and including a plurality of magnet assemblies positioned along said surface and generating magnetic fields, each of said magnet assemblies including at least one magnet defining a pair of opposite magnetic poles;

at least some of said magnet assemblies each producing a bipolar magnetic field at said surface extending generally transverse to said pathway with respect to movement of said at least one automated-guided vehicle along said pathway;

said sensor assembly made up of a plurality of magnetic sensors arranged generally transverse to said pathway, said sensor assembly positioned at said body for sensing the bipolar magnetic field of each said magnet assembly as said body is transported over that magnet assembly by said wheels, said sensor assembly producing an output indicative of magnitude and polarity of respective portions of the bipolar magnetic field sensed by said magnetic sensors;

said navigation and guidance system receiving said output from said sensor assembly and determining from said output locations of the substantially maximum magnitude of the polarities of the bipolar magnetic field sensed by said sensor assembly at each said magnet assembly, wherein said navigation and guidance system determines a position of said body with respect to a magnet assembly as said sensor assembly passes over that magnet assembly from the substantially maximum magnitudes of the polarities of the bipolar magnetic field sensed by said sensor assembly; and

wherein said navigation and guidance system determines a correction factor for correcting offset between the substantially maximum magnitude of the polarities and a predetermined location on that magnet assembly including correcting for any skew of the bipolar magnetic field with respect to said pathway for that magnet assembly, wherein said navigation and guidance system corrects the position of said body with respect to a magnet assembly with said correction factor for that magnet assembly.

15. The automated-guided vehicle system in claim 14 wherein said navigation and guidance system determines the location of maximum magnitudes of the polarities of the bipolar magnetic field by mathematically fitting at least one curve to a portion of the bipolar magnetic field sensed by said magnetic sensors and determining a maximum value of the at least one curve.

16. The automated-guided vehicle system in claim 15 wherein said mathematically fitting at lease one curve includes providing a quadratic fit to at least some of the portions of the magnetic field sensed by said magnetic sensors.

17. The automated-guided vehicle system in claim 15 wherein said navigation and guidance mathematically fits a curve to each of the opposite polarities of the bipolar magnetic field at each said magnet assembly and determines a maximum value of each curve.

18. The automated-guided vehicle system in claim 17 wherein said navigation and guidance system determines said correction factor from locations of respective maximum values of curves fitted to the opposite polarities of the bipolar magnetic field.

19. The automated-guided vehicle system in claim 14 including a plurality of vehicle initiation locations to said pathway, each of said vehicle initiation locations including at least two said magnet assemblies, wherein said navigation and guidance system responds to an orientation of the bipolar magnetic fields of the at least two magnet assemblies.

20. The automated-guided vehicle system in claim 19 wherein the orientations of the bipolar magnetic fields are unique to each of said initiation locations, thereby allowing said navigation and guidance system to distinguish one of said initiation locations from other of said initiation locations.

21. The automated-guided vehicle system in claim 19 wherein the orientations of the bipolar magnetic fields are unique for orientation of each of said initiation locations with respect to said pathway, thereby allowing said navigation and guidance system to determine an orientation that said at least one automated-guided vehicle is initiated to said pathway.

22. The automated-guided vehicle system in claim 14 wherein said at least one magnet for at least some of said magnet assemblies is a permanent magnet.

23. The automated-guided vehicle system in claim 22 wherein said pair of opposite magnetic poles for said at least some of said magnet assemblies is defined by opposite magnetic poles of one magnet.

24. The automated-guided vehicle system in claim 22 wherein said pair of opposite magnetic poles for said at least some of said magnet assemblies is defined by opposite magnetic poles of two magnets.

25. The automated-guided vehicle system in claim 14 wherein at least one of said opposite magnetic poles for at least some of said magnet assemblies is defined by an electromagnet.

26. The automated-guided vehicle system in claim 24 wherein said electromagnet is selectively actuated to provide a signal to said at least one automated-guided vehicle as said sensor assembly passes over the associated magnet assembly.

27. The automated-guided vehicle system in claim 14 wherein said predetermined location of that magnet assembly comprises a pole face corresponding to the at least one polarity.

L6: Entry 13 of 30 File: USPT Sep 3, 2002

DOCUMENT-IDENTIFIER: US 6445984 B1
TITLE: Steer control system for material handling vehicles

Abstract Text (1):
The present invention is a method and apparatus for controlling a steer center position of an automatic guided vehicle (AGV) of the type that follows a wire. As the automatic vehicle follows a wire, the distance of the AGV from the wire is monitored over a given distance, and an average distance from wire calculated. This value is used to determine a steer center position adjustment, which adjusts the steer center position to maintain the AGV within a predetermined distance of the wire or other path. The present invention is useful in accounting for variations between AGV's based on mechanical linkages and manufacturing differences; differences in steer center position when an AGV is driven in a forward or reverse direction; and changes due to environmental conditions.

Brief Summary Text (5):
To accommodate these changes, automated guided vehicles have become increasingly common. Automated guided vehicles (or AGVs) are vehicles which are guided automatically along an established path such as along a wire in the floor of a warehouse. AGV's can be unmanned vehicles for carrying parts or components in a manufacturing plant or manned vehicles which carry an operator and provide material handling functions such as order picking, lifting, or reaching. When used in conjunction with a central processing system, the storage and retrieval of specific items can be quickly and easily controlled from a central location, essentially without the need for human intervention. These devices, therefore, make warehousing operations both more efficient and less expensive than prior art manual systems.

Brief Summary Text (6):
Although AGVs can increase efficiency and lower the cost of warehousing operations, automatic vehicles present a number of problems for users. To prevent damage to the racking and shelving used to store materials, as well as to the vehicle itself, and to prevent damage to stored materials, for example, the AGV must be prevented from veering into racking at the sides of the path, or into stock stored temporarily in locations within an aisle or pathway. It is important, therefore, that AGVs move within a predetermined, closely defined path.

Brief Summary Text (7):
Due to these restrictions, steering control systems are vitally important in AGVs. One important parameter for controlling the motion of an AGV is the identification of a steer center position. The steer center position identifies the angle at which the steer motor or other steering device must be directed to drive the AGV in a straight direction. To a close approximation, the steer center position can be established by switches or other indicating devices mounted to the steer mechanism. However, errors in this position can be introduced by mechanical linkages and gear systems in the drive system of the vehicle, by environmental factors in a warehouse, or simply due to changes in control as the AGV is used. To prevent wandering due to these various errors, prior art systems often included a "learn" mode for teaching a steer center position to an AGV. In the learn mode, the control system learns the position of a feedback device (such as an encoder) while the AGV

is driven along a straight path. While adequate in some applications, however, there are a number of disadvantages associated with the "learn mode" process. First, additional hardware such as key pads or switches are required to establish a learn mode. Second, once established, the steer center position is not automatically adjusted for varying conditions. Furthermore, the learn mode cannot easily adjust for manufacturing errors related to mechanical linkages and home switches, and therefore can make the manufacture of AGVs difficult.

Brief Summary Text (8):
There remains a need, therefore, for an improved method and apparatus for determining a steer center position for an AGV. Such a method would preferably allow an AGV to automatically learn a steer center position during normal operation, and would automatically modify the steer center position as environmental and mechanical conditions change. The method would also account for errors induced by mechanical linkages, environmental conditions, and general usage of the AGV.

Brief Summary Text (10):
The present invention is a method and apparatus for determining a steer center position for an automatic guided vehicle which follows a wire. As the vehicle moves along a guide wire, the distance of the vehicle from the wire is monitored. At a predetermined maximum travel distance, the average distance from wire over the distance traveled is calculated, and the average distance from wire is used to determine an adjustment to the steer center position. Adjustment to the steer center position, therefore, relies almost entirely on a single variable: the average distance from wire.

Brief Summary Text (11):
The method of the present invention can be used to allow an AGV, and particularly an order picker forklift, or other manned material handling vehicle, to "learn" a steer center position, where an initial steer center position, determined by crossing home switches or other known means, is adjusted by a steer center adjustment value to account for differences in the AGV topology due to manufacturing tolerances, mechanical linkages, differences in steer center position in forward and backward motion, misalignment in the construction of the chassis and other factors. Furthermore, the method can be used to adapt the steer center position for changes induced during use. Such changes can occur, for example, due to wear on mechanical parts, adjustments made during maintenance or service of equipment, warehouse environmental factors, damage to home centering switches or switch-activators, or other factors. The present invention eliminates the need for reliance on accurate home switches and specialized "learn" modes which must be run to establish a steer center position. The present system can also be used to adapt the steer center position during operation, and therefore to maintain the vehicle within a predetermined distance of a predetermined path, particularly a guide wire path.

Drawing Description Text (2):
FIG. 1 is a schematic of an AGV constructed in accordance with one embodiment of the invention.

Drawing Description Text (3):
FIG. 2 is a perspective view of the traction and steer system of the AGV of FIG. 1.

Drawing Description Text (4):
FIG. 3 is an overhead view of the AGV of FIG. 1.

Drawing Description Text (5):
FIG. 4 is a block diagram of the control system of the AGV of FIG. 1.

Drawing Description Text (6):
FIG. 5 is a flow chart for a method for determining a steer center position adjust for the AGV of FIG. 1.

Drawing Description Text (8):
FIG. 7 is a graph illustrating a typical steer center position adjust versus average distance from wire

Drawing Description Text (10):
FIG. 9 is a block diagram of a simplified control system for an AGV constructed in accordance with the present invention.

Detailed Description Text (2):
Referring now to the FIGS., and more particularly to FIG. 1, a schematic view of an automatic guided vehicle 10 (AGV 10) constructed in accordance with the present invention is shown. The AGV 10 as shown and described is particularly adapted for use as a manned material handling vehicle such as an order picker, forklift, stacking vehicle, or other warehousing device. However, the principles associated with the present invention can be applied to a number of automated vehicles. The term AGV will be used to refer to all partial or fully automatically guided vehicles, both manned and unmanned.

Detailed Description Text (3):
The AGV 10 comprises four basic systems: a drive system 12, a manual steering system 14, a control system 18, and a distance from wire detection circuit 16. In general, the control system 18 receives AGV position, AGV velocity, and steer feedback data including an initial steer center position from the drive system 12; distance from wire (DFW) data from the wire detection circuit 16; and steer center adjust data from memory or storage components internal to the control system 18. Based on this input data, the control system 18 calculates adjustments to the steer and calculates command signals for the drive system 12 to control the steer direction of the AGV. A specific embodiment of an AGV including each of these systems will be described more fully below.

Detailed Description Text (4):
Referring again to FIG. 1, in one embodiment of the invention, the distance from wire detection circuit 16 comprises a plurality of antennae 38 which are employed to detect the lateral distance of the AGV 10 from the guide wire 40 in accordance, for example, with the method disclosed in U.S. Pat. No. 5,519,296, to Day. U.S. Pat. No. 5,519,296 is hereby incorporated by reference as an example of one method for determining the DFW between the AGV 10 and the wire 40. Other methods known to those of skill in the art could also be employed to determine the DFW.

Detailed Description Text (5):
The manual steering system 18 comprises an AUTO/MANUAL switch 42 which can be selectively activated by the user to remove the AGV 10 from an automatic guided mode (AUTOMATIC mode), and to instead allow the AGV to be navigated by the steer tiller 44 (MANUAL mode). The steer tiller 44 includes a manual steering encoder 46 which provides steering directional information to the control system 18 for selecting a steering direction when the AGV 10 is operated in the MANUAL mode.

Detailed Description Text (6):
Referring now to FIG. 2, the drive system 12 comprises two major parts: a steer motor assembly 21 and a drive motor or traction assembly 23. The steer motor assembly 21 comprises a steer motor 20 coupled to a triple reduction gear box 30 and a pinion gear 32. A steer feedback encoder 26 is coupled to a shaft of the steer motor 20, and provides steer feedback data to the control system 18. Preferably, the drive system 12 also includes one or more home switches 39 operated by the cam 36 to determine an approximate initial steer center or home position of the steer motor prior to movement of the AGV 10. Preferably, the drive system 12

includes a plurality of home switches . The home switches can be located at the initial steer center position or at known offsets from the initial steer center position.

Detailed Description Text (7):
The traction assembly 23 comprises a drive motor 22 coupled to a swivel bearing 37, a cam 36, a ring gear 34, and a drive tire 24. The traction assembly 23 further includes a drive motor encoder 28 which provides AGV position data to the wire guidance control 50. The drive motor encoder 28 can also provide information regarding the direction of motion of the AGV 10, i.e. whether the AGV 10 is moving in the forward (tractor first) or backward (fork first) directions.

Detailed Description Text (8):
The steer motor assembly 21 is coupled to the traction assembly 23 through the interface of the ring gear 34 and the pinion gear 32 such that, as the pinion gear 32 is rotated, the ring gear 34 causes the tire 24 to rotate on the swivel bearing 37. Because there are four gear meshes between the steer encoder 22 and the actual position of the swivel bearing 37 (namely, the triple reduction gear 30 and the pinion gear 32), there is a significant degree of backlash between the positional data from the steer feedback encoder 26 and the actual steered direction of the tire of the AGV 10. This backlash introduces an error into the steer center position, which can be as much as two degrees depending on the wear of the gears. Furthermore, referring also to FIG. 3, the chassis 29 of the AGV 10 is a tricycle chassis comprising the drive tire 24, and two load tires 41 and 43. In this chassis 29, the drive tire 24 is offset from center. The offset allows the use of a less expensive casting 27 for mounting the tire 24 but also induces a net steering torque on the steered unit which can induce an additional error in the steer center position. In addition, because of the offset, there is a difference in a steer center position when driving in the forward (tractor first) direction and backward (fork first) directions. Additional differences between AGV's exist due to variations in manufacturing, failure to fall within mechanical tolerances, errors in welding the chassis which can cause the truck to "dog track," etc. The combined effect of these errors is an offset between the steer feedback encoder 26 data received by the vehicle manager 48, and the actual steer direction of the AGV 10. To correct for this offset, an adjustment must be made to the instantaneous feedback from the steer feedback encoder 26. The adjustment is equal to the difference between the initial steer center position as determined by the home switches and the actual steer center position, i.e. the steer position at which the AGV 10 travels straight ahead along the wire. Due to mechanical differences encountered in driving the AGV 10 forward or backward, a separate adjustment is acquired for each direction. The magnitude of the steer units adjustment is determined through the steer center adjustment method discussed with reference to FIG. 5 below, which provides adaptive adjustment of the steer center position, to address both mechanical and operational conditions. Although a drive system 12 comprising a steer assembly 21 and traction assembly 23 coupled to a single tire 24 is shown, it will be apparent to one of ordinary skill in the art that, in some applications the steer assembly and traction assembly could each be coupled to a separate tire, wherein the steer assembly and associated tire provide a steer function, and the traction assembly and associated tire provide traction. Other topographies will also be apparent to those of skill in the art.

Detailed Description Text (9):
Referring again to FIG. 1, the control system 18 comprises two control circuits, the wire guidance control 50 and the vehicle manager 48. The wire guidance control 50 and vehicle manager 48 are communicatively coupled via the data bus 52. Referring now to FIG. 4, a block diagram of the control system 18 is shown. The wire guidance control 50 comprises CPU 54, an analog to digital convertor 56, a memory component 55, and a transceiver 58 for transmitting data to and receiving data from the vehicle manager 48 along the data bus 52. The wire guidance control 50 receives analog input signals indicative of the DFW and employs a method of the

type described in U.S. Pat. No. 5,519,296, cited above, to calculate a digital DFW value. The wire guidance control 50 also receives AGV positional data from the traction encoder 28. The CPU 54 determines the position of the AGV 10 based on this information, and also calculates a velocity of the AGV 10 by differentiating the positional data. The velocity data provides a scalar speed of the AGV 10, and is signed to indicate a direction of motion. The DFW value, AGV position data, and AGV speed data are all transmitted to the vehicle manager 48 via the data bus 52. As shown in FIG. 4, the transceiver 58 and 60 used in each of the wire guidance control 50 and the vehicle manager 48 is preferably a Controller Area Network (CAN) transceiver, and the data bus 52 is therefore preferably a CAN bus. It will be apparent to those of ordinary skill in the art, however, that other communication methods can also be used.

Detailed Description Text (11):
In the MANUAL mode, as determined by the position of the AUTO/MANUAL switch 42, the vehicle manager 48 receives input data from the manual encoder 46, which establishes a command steer direction; the steering feedback encoder 26, which provides steer feedback data regarding the actual steer position of the steer motor 20; and the traction encoder 28 which provides the velocity and actual position data for the AGV 10 to the vehicle manager 48 and to the wire guidance control 50 through the data bus 52. The command steer direction from the manual encoder 46 and the steer feedback data from the steering feedback encoder 26 are employed in a typical control loop for providing a control signal to drive the steer motor 20 to maintain the direction of the AGV 10 in the direction requested by the manual encoder 46.

Detailed Description Text (12):
In the AUTOMATIC mode the steer motor 20 is initially slewed to determine an initial steer center position. Preferably, the home switches 39 established both a forward and backward steer center position. The steer center position is adjusted by adding the stored forward and backward steer center position values, respectively, the vehicle manager 48 determines a command steer direction for directing motion of the steer motor 20 from the DFW data, which is proportional to the required command values to drive the AGV 10 along the wire. The vehicle manager 48 also receives data from the steer feedback encoder 26 which is stored in RAM 68 and which is adjusted by the steer center adjustment value retrieved from the EEPROM 66, to account for mechanical linkages and other factors as described above. The vehicle also receives AGV position, and AGV velocity data from the wire guidance control 50 via the data bus 52. The DFW data, and the adjusted steer feedback data from the steer feedback encoder 26 are employed in a typical control loop for providing a control signal to drive the steer motor 20 to maintain the direction of the AGV 10 in the direction requested.

Detailed Description Text (13):
During AUTOMATIC operation, the vehicle manager 48 also monitors the average lateral DFW and determines a steer center adjustment value such that the AGV 10 "learns" the actual steer center and can be maintained within a reasonable distance of a predetermined path as noted above, an initial steer center position is determined by the position of the home switches 39 and the stored forward and backward steer center adjustment value, described more fully below. The steer center adjustment level is modified in operation based on the average DFW over a predetermined distance, also as described more fully below.

Detailed Description Text (15):
Minimum Speed--a predetermined minimum speed level which the AGV must exceed before DFW data is examined

Detailed Description Text (16):
AGV Speed--the instantaneous speed of the AGV

Detailed Description Text (17):
Travel Increment--a predetermined incremental travel distance along the length of the wire at which DFW readings are taken for the AGV

Detailed Description Text (18):
Travel Sum--an ongoing count of the number of Travel Increments an AGV has traveled

Detailed Description Text (20):
Travel Distance--an ongoing measure of the distance traveled by the AGV between Travel Increments

Detailed Description Text (21):
Maximum Distance--a predetermined maximum distance comprising a predetermined integer number of Travel Increments

Detailed Description Text (22):
DFW Average--the average DFW determined as the DFW Sum divided by the Maximum Distance

Detailed Description Text (23):
On power-up of the AGV 10, the steer motor 20 is rotated to activate the home switches.

Detailed Description Text (24):
Each home switch provides a signal indicative of a known steer position for calibrating actual steer position of the AGV 10 versus the steer feedback encoder 26 data. Through this process, an initial steer center position for each of the forward (Forward Steer Center Position) and backward directions (Backward Steer Center Position) of the AGV 10 is determined based on the crossing of the home switch and the steer feedback encoder 26 data.

Detailed Description Text (26):
Referring again to FIG. 5, when the AGV 10 is in the AUTOMATIC mode as determined by the AUTO/MANUAL switch 42, and is driven in either direction, the vehicle manager 48 continually monitors the AGV Speed (step 102) through data received from the wire guidance control 50. If the AGV Speed is determined to be below the Minimum Speed, the Travel Distance, DFW Sum, and Travel Sum are set to zero (step 104). When the AGV Speed is found to exceed the Minimum Speed, the vehicle manager 48 monitors the Travel Distance until the Travel Distance is equal to or greater than the Travel Increment (step 106). When the Travel Increment is met or exceeded, the DFW is retrieved from the data bus 52 and is summed with the DFW Sum, the Travel Sum is incremented to include the Travel Increment, and the Travel Distance is reset to zero (step 108). The AGV Speed is monitored, DFW readings are taken, and the DFW Sum and Travel Sum are incremented at each Travel Increment until the Maximum Distance is reached (step 110). Referring now to FIG. 6, when the Maximum Distance is reached, the DFW Average is determined by dividing the DFW Sum by the number of Travel Increments in the Maximum Distance (step 112), and the DFW Sum, Travel Sum, and Travel Distance are reset to zero.

Detailed Description Text (28):
After the steer center adjustment value is interpolated, the direction of motion of the AGV 10 is determined, as described above with reference to the drive motor encoder 28 (Step 116). The steer center adjustment value is added to the steer center adjustment (the Forward or Backward Steer Center Adjustment) value associated with the determined direction of motion (steps 118 and 120). The steer center adjustment value can then be stored as a variable in RAM 68, or can be stored in EEPROM 66 as described more fully below. The steer center adjustment value is added to the steer feedback encoder data to account for differences between actual steer unit position and steer feedback encoder data 26 due to any of

the factors discussed above. The adjusted steer feedback data is used by the vehicle manager 48 along with DFW data as a feedback to a PID or other standard control loop to maintain the AGV 10 within a predetermined distance of the guide wire 40.

Detailed Description Text (29):
In a preferred embodiment of the invention, the AGV Minimum Speed was selected to be one mile per hour, the AGV Travel Increment was selected to be a distance of one foot, and the AGV Maximum Distance was selected as a distance of ten feet. These selected values were determined experimentally to adjust the steer center position efficiently even when the AGV moves along short aisles. However, it will be apparent that other values could be used, and may be advantageous for AGV's with different mechanical configurations, or which travel in different environments and conditions. Furthermore, although a specific method for calculating a DFW Average has been shown and described, it will be apparent that a number of different known methods for calculating average values could be used. Additionally, it is also possible to vary the increments at which DFW readings are taken, and make other modifications to the method shown without departing from the scope of the invention. Furthermore, the Travel Increment can be determined as a function of data from the drive motor encoder 28, or calculated by the vehicle manger 48 as a function of AGV speed multiplied by time.

Detailed Description Text (30):
Referring to FIG. 7, a graph illustrating the DFW Average versus steer center adjust value is shown. Here, DFW Average in inches is plotted versus a correction of the steering angle in degrees. In this embodiment, the steer center adjustment is non-linear, in that a comparatively large steer center adjust is applied to a large DFW average, and a smaller steer unit adjust factor is applied when the DFW average is relatively small. This adaptive correction function prevents oscillation of the AGV 10 from one side to another when the DFW is small, and also provides rapid conversion for large errors. If the DFW Average extends outside of a predetermined range, an illegal zone is entered and the steer center adjust is set to zero. An example of a look-up table constructed from the graph of FIG. 5, could, for example, include an array of steer center adjustment values in degrees. As noted above, the DFW Average is used as an index, and values between the data points are interpolated. Although a non-linear graph is shown, it will be apparent that in some applications a linear relationship between DFW average and steer center adjust may be appropriate. Furthermore, the adjustment data shown was developed for a specific application, and can be adapted as necessary for different mechanical configurations or environmental conditions.

Detailed Description Text (31):
Preferably, once a steer center adjustment value is determined, it is stored in memory for later retrieval. The preferred memory storage is the electrically erasable programmable read only memory EEPROM 66 of the vehicle manager 48, or a similar nonvolatile storage device which retains the value during power-down of the vehicle but which allows changes to the value when necessary. To prevent wear out of the EEPROM 66 from overuse, the number of times the EEPROM 66 is erased and overwritten is preferably limited to, for example, a single write for every power-on of the AGV, or to a write when the steer center adjustment value exceeds a predetermined maximum limit value.

Detailed Description Text (33):
Although a specific AGV 10 and a specific control system have been shown and described, it will be apparent to one of ordinary skill in the art that a number of modifications could be made to the described elements without affecting the scope of the invention. For example, referring to FIG. 9, a block diagram illustrating simplified control system 200 for a wire guided AGV constructed in accordance with the present invention is shown. The simplified control system 200 comprises a CPU 202 and a memory component 204 comprising a nonvolatile random access memory

component (or EEPROM) 204a, a random access memory component 204b, and a read only memory component 204c. Inputs to the control system 200 are provided by a traction feedback encoder 210, a steering feedback encoder 208, and a DFW detector 206. Outputs from the control system 200 are provided to a steer motor 214 and a drive motor 212. The control system 200 can comprise one or more microprocessor or microcontroller, including appropriate I/O interfaces, A/D convertors or other signal processing elements, and memory components such as those delineated as components 204a-c. Furthermore, while the construction of the AGV 10 is shown to include an offset tire and backlash in the steer motor assembly 12, the disclosed steer center position adjust method is applicable to all automatic guided vehicles with a three wheel "tricycle" steering geometry and in a conventional 4 wheel geometry with 2 steered wheels. The steer control system of the present invention can be employed to correct for any number of mechanical linkage, environmental manufacturing errors, or usage induced errors to the steer center position. Furthermore, the construction of the steer system 12 can be geared in a number of ways known to those of skill in the art. For example, the steer feedback encoder 26 can be geared directly off the ring gear. This construction would reduce the number of gear meshes but increase costs. In addition, other types of data storage could be used in place of the described look up table and in some applications, steer units adjust values could be calculated rather than stored as tabular data. As noted above, there are a number of known ways for performing the calculations of the steer center adjust method, and modifications of this type can be made within the scope of the invention.

CLAIMS:

1. A method for determining a steer center position for an automatic guided vehicle of the type which travels along a guide wire, the method comprising the following steps: monitoring a distance traveled by the automatic guided vehicle; establishing a plurality of predetermined travel increments in a predetermined total distance; determining a distance from wire value for the automatic guided vehicle at each predetermined travel increment; calculating an average distance from wire over the number of predetermined travel increments in the predetermined total travel distance; and adjusting the steer center position, wherein the adjustment is a function of the average distance from wire.

3. The method as defined in claim 2, further comprising the steps of determining whether the direction of travel of the automated guided vehicle is forward or backward and adding the adjustment to the steer center position to the forward steer center position when the direction is forward and to the backward steer center position when the direction is backward.

4. The method as defined in claim 1, wherein the step of adjusting the steer center position comprises retrieving an adjustment value from a look-up table which correlates the average distance from wire to a steer center adjust value.

6. The method as defined in claim 4, further comprising the step of assigning zero to the steer center adjust value when the distance from wire value is outside of a predefined range of accepted values.

8. The method as defined in claim 4, wherein the steer center position adjustment values of the look-up table are selected to prevent oscillation of the automatic guided vehicle on the wire when the average distance from wire is small.

9. The method as defined in claim 4, wherein the look-up table includes relatively small steer center adjustment values when the average distance from wire is small, and relatively large steer center adjustment values when the average distance is large.

10. The method as defined in claim 1, wherein the steer center adjustment values

increase non-linearly as the average distance from wire increases.

11. The method as defined in claim 1, wherein the predetermined travel distance increment is one foot and the predetermined total distance is ten feet.

13. The method as defined in claim 1, further comprising the steps of summing the distance from wire values for each of the predetermined travel increments and calculating the average distance from wire as the sum of the distance from wire values over the number of predetermined travel increments in the predetermined total travel distance.

14. The method as defined in claim 1, wherein the step of establishing a plurality of predetermined travel increments comprises determining each predetermined travel increment by integrating the speed of the AGV over the time that the AGV has been in motion.

15. An apparatus for adjusting a steer center position for an AGV, the apparatus comprising: a central processing unit; a distance from wire detector electrically coupled to the central processing unit; a drive traction feedback encoder electrically coupled to the central processing unit; a steer feedback encoder electrically coupled to the central processing unit; a read only memory component electrically coupled to the central processing unit, the read only memory component storing data correlating distance from wire to steer center position adjust data; and a nonvolatile random access memory component electrically coupled to the central processing unit, the nonvolatile random access memory component storing a steer center position value, wherein the central processing unit is programmed to: retrieve the steer center position value from the nonvolatile random access memory; monitor an output signal from the drive traction encoder to determine an instantaneous travel position of the AGV and a total travel distance; monitor an output signal from the distance from wire detector to determine an instantaneous distance from wire value at a plurality of travel positions; monitor an output signal from the steer feedback encoder: calculate an average distance from wire over the total travel distance; retrieve a steer center position adjust value correlated to the average distance from wire from the read only memory; and adjust the output signal from the steer feedback encoder by the steer center position adjust value.

17. The apparatus as defined in claim 15, wherein the central processing unit is further programmed to differentiate the output signal from the traction encoder with respect to time to determine an instantaneous speed, to compare the instantaneous speed to a predetermined minimum value, and to monitor travel distance and distance from wire data only when the predetermined speed is exceeded.

20. An automatic guided vehicle (AGV) of the type that follows a wire, the AGV comprising: a steering assembly including a steer motor and a steer feedback encoder; a traction assembly including a drive motor, a drive motor encoder, and a drive tire, the traction assembly being coupled to a tractor chassis of the AGV to provide a motive force to the AGV; a control system, electrically coupled to the steer motor, the steer feedback encoder, the drive motor, and the drive motor encoder; and a distance from wire detector electrically coupled to the control system, wherein the control system is programmed to: receive a feedback position signal from the drive motor encoder, a distance from wire signal from the distance from wire detector, and steer encoder feedback data from the steer feedback encoder; calculate an average distance from wire over a predetermined distance; calculate an adjustment of a steer center position based on the average distance from wire; calculate an adjusted steer encoder feedback as the sum of the steer feedback encoder data and the adjustment of the steer center position. calculate a command to the steer motor based on feedback from the distance from wire detection and the adjusted steer encoder feedback.

24. The automatic guided vehicle as defined in claim 20, wherein the control system calculates the average distance from wire over a predetermined distance by performing the following steps: calculate a speed of the automatic guided vehicle; compare the speed to a predetermined minimum speed; when the speed of the automatic guided vehicle exceeds the predetermined minimum speed, begin to calculate a travel distance; compare the travel distance to a predetermined travel increment; at each predetermined travel increment up to a maximum travel distance, storing a distance from wire value at each travel increment; when the maximum travel distance is reached or exceeded, calculating a sum of the distance from wire measurements and calculating an average distance from wire over the maximum distance.

25. A method for tuning a steer center position of an automatic guided vehicle of the type which travels along a guide wire, the method comprising the following steps: slewing a motor to trip a home switch; storing an initial steer center position correlating to the position at which the home switch is tripped; monitoring a distance traveled by the automatic guided vehicle; establishing a plurality of predetermined travel increments in a predetermined total distance; determining a distance from wire value for the automatic guided vehicle at each predetermined travel increment; calculating an average distance from wire over the number of predetermined travel increments in the predetermined total travel distance; and adjusting the initial steer center position to account for differences between the initial steer center position and the steer center position, wherein the adjustment is a function of the average distance from wire.

26. The method as defined in claim 25, further comprising the step of adjusting the initial steer center position by a steer center adjustment prior to determining the distance from wire.

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L6: Entry 6 of 30 File: PGPB Jun 24, 2004

DOCUMENT-IDENTIFIER: US 20040122570 A1
TITLE: Automated guided vehicle, operation control system and method for the same, and automotive vehicle

Summary of Invention Paragraph:
[0002] Conventionally, running control of an automated guided vehicle used for an automated guided vehicle system, which is intended to be automatized and laborsaving, generally employs a guidance system by fixed routes without tracks, which is advantageous in view of the cost and technology. Such fixed routes are determined by guidance lines, for example guidance tapes attached on the floor of an unmanned warehouse or a factory. An automated guided vehicle runs automatically along the guidance lines while detecting the guidance lines electromagnetically or by means of an optical system using a line detection sensor. Such guidance lines are generally formed as continuous or circular running routes and designed such that short-circuit running paths and charging areas are provided at several places along the route. At appropriate positions outside and along the circular guidance lines, a plurality of work stations are positioned for loading and unloading articles to be transported, and charging stations are positioned inside the circular path.

Summary of Invention Paragraph:
[0012] For example, in the case of the conventional communication by way of RS232C, a data transmission rate was 9.6 Kbps, and it took about 3 seconds to transmit running data from the operation control unit to the automated guided vehicle and about 0.5 second for transmission of a start instruction, so that a total of about 3.5 seconds was required. Therefore, a waiting time of about 3.5 seconds was necessary from the time a transport is completed until the next transport starts.

Summary of Invention Paragraph:
[0014] Furthermore, the automated guided vehicle runs from the time 20 units of automated guided vehicles intend to enter a designated area until a start allowance is given at an average distance L of L=20.times.0.5 sec.times.0.66=6.6 m by setting the speed of the automated guided vehicle to be 40 m/minute. Therefore, for conducting a blocking control to avoid collisions between the automated guided vehicles, it was necessary either to provide a confirmation section of at least about 6.6 m for communication to confirm whether it is allowed to enter just before entering the designated area, or to stop the automated guided vehicle every time at the entrance of the designated area to confirm whether it is allowed to enter so as to send a start instruction. Therefore, there was a problem of loss in area productivity due to the extra running space of the confirmation section, and there was also a problem of loss in time since the automated guided vehicles stopped at the entrance every time even if there was no other automated guided vehicle in the designated area.

Summary of Invention Paragraph:
[0031] Moreover, the automated guided vehicle preferably includes detection means for detecting a mark or another distinction means on a running path located at a position before an entrance of the designated area sufficient to provide a running distance allowing stopping before the entrance, and the automated guided vehicle

obtains area entry information also while running based on a detection of the distinction means by the detection means.

Detail Description Paragraph:
[0070] FIG. 2 is a block diagram showing the schematic configuration of the wireless LAN adapter 11 of FIG. 1. In FIG. 2, 16 is a two-way antenna of radio-frequency signals (hereinafter abbreviated as RF signals, but it is not limited to RF signals and can be, for example, optical signals), 21 is a filter for suppressing unnecessary frequencies, and as the filter 21, for example, a band-pass filter or the like is used. 22 is a RF switch for switching between transmission and reception; 23 is a RF amplifier for amplifying RF signals to be received; 24a is a mixer serving as an up-converter for conversion of frequencies into higher spectra; 24b is a mixer serving as a down-converter for conversion of frequencies into lower spectra; 25 is an IF amplifier for amplifying intermediate-frequency signals to be received (hereinafter abbreviated as IF signals); 26 is a SAW (Surface Acoustic Wave) matched filter for demodulating spread spectrum signals; 27 is a determination circuit for converting demodulated signals into serial data; 28 is a conversion circuit for converting serial data into parallel data (hereinafter abbreviated as a SIO); 29 is a CPU for processing of data and control of each part; 30 is an Ethernet controller for passing data with the Ethernet cable 15 (other interface controllers such as a PCMCIA controller can be used as well); 31 is a modulation circuit for performing a primary modulation such as a quadrature phase shift keying (hereinafter abbreviated as a QPSK modulation circuit) on data signals; 32 is a generation circuit of pseudonoise codes (hereinafter abbreviated as a PN code) for performing spectral diffusion (hereinafter abbreviated as a PN generation circuit); 33 is an amplifier for amplifying transmission signals; 34 is a voltage control oscillator for generating IF reference signals (hereinafter abbreviated as a VCO); 35 is a VCO for generating RF reference signals; and 36 is a power amplifier for amplifying RF signals ultimately.

Detail Description Paragraph:
[0086] Furthermore, the information on start instructions and other messages transmitted from the operation control unit 41 or the automated guided vehicle 1 include an identification number of the operation control unit 41 or a task identification number. Thus, the automated guided vehicle 1 etc. that received a message can check the identification number included in the message and confirm whether it is an authorized message to be received or an error message. In this way, processing of any error message from the network computer for ordinary work 43, which is connected to the LAN 44 but does not contribute to operation control, or from the automated guided vehicle 1 is prevented.

Detail Description Paragraph:
[0097] FIG. 5B, FIG. 5C and FIG. 5D show one configuration example of a position and status information file stored in automated guided vehicles AGV1, AGV 2 and AGV 3 of FIG. 5A, respectively. FIG. 5B, FIG. 5C and FIG. 5D show examples in which the "status" is indicated either as "in transport" or "waiting for transport request", but different status such as "charging" or "stopping due to trouble" are also possible.

Detail Description Paragraph:
[0118] In addition, when the blocking data are checked by the automated guided vehicle 1 at the time a detection mark that is provided before the entrance mark of the merging area A1 at a predetermined distance (for example, 60 cm) is detected, the automated guided vehicle 1 can stop at the entrance mark in the case where the merging area A1 is not open. Here, the above-mentioned distance is predetermined by considering a distance that is sufficient for the automated guided vehicle 1 to stop surely before reaching the entrance of the merging area A1. Furthermore, in the case of using the entrance mark as a detection mark, the entrance mark can be shifted from the merging area and positioned at a predetermined distance (for example, 1 meter) before the merging area, so that the automated guided vehicle 1

can check the blocking data at the time the entrance mark is detected and stop within 1 meter from the entrance mark when the merging area A1 is not open. Here, the above-mentioned distance is predetermined by considering a distance that is sufficient for the automated guided vehicle 1 to stop before reaching the entrance of the merging area A1.

Detail Description Paragraph:
[0119] Moreover, by passing information among a plurality of automated guided vehicles via the built-in wireless LAN adapter 11, without interposing the operation control unit 41, and determining whether to enter the merging area, it is also possible to check mutually the routes of the other vehicles and to allow the other vehicle to take the running path. Accordingly, the load on the side of the operation control unit 41 can be reduced.

Detail Description Paragraph:
[0130] Furthermore, for conducting a blocking control to avoid collisions between automated guided vehicles, when, for example, 20 units of automated guided vehicles are positioned, it was necessary to provide a run-up of at least 6.6 m before a merging area in the past, which corresponds to an average distance for an automated guided vehicle to run from the time the automated guided vehicle intends to enter a designated merging area until a start allowance is given. However, according to the present embodiment, a required run-up is 6.6.times.9.6/11000=0.0058 m=5.8 mm, so that essentially a run-up is no longer necessary. Thus, a start allowance can be given without stopping the automated guided vehicle, and it is not only possible to reduce the area of merging areas where only one vehicle can enter but also to conduct the blocking control without stopping the automated guided vehicle. As a result, the transport capability of the automated guided vehicle can be improved.

CLAIMS:

1. (Amended) an automated guided vehicle for conducting a transport of articles or other work by running a designated running route, the automated guided vehicle comprising a wireless local area network adapter for passing or referring to information or software needed for running in the automated guided vehicle by radio between an external device connected to the local area network or between another automated guided vehicle, a memory part for storing at least information passed or referred to from the external device or from the another automated guided vehicle and information related to the automated guided vehicle itself, and a control part for controlling the wireless local area network adapter and the memory part.

2. The automated guided vehicle according to claim 1, wherein the automated guided vehicle refers to and timely obtains information needed for running of the automated guided vehicle, which is stored in the external device or in another automated guided vehicle, by itself via the wireless local area network adapter, and running control is conducted by itself based on the obtained information.

3. The automated guided vehicle according to claim 2, wherein as the information needed for running, the automated guided vehicle timely obtains running data indicating running routes by itself via the wireless local area network adapter.

4. The automated guided vehicle according to claim 2, wherein as the information needed for running, the automated guided vehicle timely obtains information on transport requests for the automated guided vehicle by itself via the wireless local area network adapter.

5. The automated guided vehicle according to claim 2, wherein the memory part stores information on the present position or status information indicating the present status so that the external device refers thereto via the wireless local area network adapter and determines an automated guided vehicle to which a transport request is output.

6. The automated guided vehicle according to claim 2, wherein as the information needed for running, the automated guided vehicle timely obtains information on start instructions for the automated guided vehicle by itself via the wireless local area network adapter.

7. The automated guided vehicle according to claim 2, wherein as the information needed for running, the automated guided vehicle timely obtains area entry information that controls the automated guided vehicle from entering a designated area of running by itself via the wireless local area network adapter, confirms whether there is any other automated guided vehicle in the designated area other than itself based on the obtained area entry information, and determines whether to enter the designated area based on the result of judgement.

8. The automated guided vehicle according to claim 7, wherein in the case where the automated guided vehicle confirms that there is no other automated guided vehicle in the designated area other than itself, the automated guided vehicle updates the area entry information, which is stored in the external device or in the another automated guided vehicle, by adding its own identification information thereto, enters the designated area and occupies the designated area.

9. The automated guided vehicle according to claim 7, wherein in the case where the automated guided vehicle confirms that there is an automated guided vehicle in the designated area other than itself, the automated guided vehicle updates area entry standby information that controls the entry standby of the designated area, which is stored in the external device or in the another automated guided vehicle, by adding its own identification information and priority thereto and waits to enter before the designated area.

10. The automated guided vehicle according to claim 7, wherein in the case where the automated guided vehicle confirms that there is no other automated guided vehicle in the designated area other than itself, the automated guided vehicle obtains area entry standby information that controls the entry standby of the designated area, which is stored in the external device or in the another automated guided vehicle, and when it is confirmed that there is no other automated guided vehicle other than itself with a higher priority based on the obtained entry standby information, updates the area entry information, which is stored in the external device or in the another automated guided vehicle, by adding its own identification information thereto, enters and occupies the designated area.

11. The automated guided vehicle according to claim 7, wherein the automated guided vehicle comprises detection means for detecting a mark or other distinction means on a running path provided in a position before an entrance of the designated area by considering a running distance enabling stopping before the entrance, and the automated guided vehicle obtains the area entry information based on a detection of the distinction means by the detection means.

12. The automated guided vehicle according to claim 2, wherein as information needed for running, the automated guided vehicle timely obtains running route change data for instructing a change of routes from a present running route to another running route by itself via the wireless local area network adapter, and runs by changing its running route to the instructed running route based on the obtained running route change data.

13. The automated guided vehicle according to claim 1, wherein the automated guided vehicle enables updating of transport control software stored in the memory part or rewriting data through remote processing via the local area network by the external device.

14. The automated guided vehicle according to claim 1, wherein the automated guided

vehicle comprises a melody reproducing device for reproducing music data stored in the memory part, the automated guided vehicle enabling rewriting the music data as appropriate through remote processing via the local area network by the external device.

15. The automated guided vehicle according to claim 1, wherein information on start instructions or other messages passed by radio with the external device or another automated guided vehicle includes at least one selected from an identification number of the external device or of the other automated guided vehicle and a task identification number.

17. The automotive vehicle according to claim 16, wherein the automotive vehicle refers to and timely obtains information needed for running of the automotive vehicle by itself, which is stored in the external device or in another automated guided vehicle, via the wireless local area network adapter, and running control is conducted by itself based on the obtained information.

18. An operation control system for an automated guided vehicle including an automated guided vehicle for conducting a transport of articles or other work by running a designated running route and an external device for passing information by radio with the automated guided vehicle, wherein the automated guided vehicle comprises a wireless local area network adapter for passing information by radio with the external device connected to the local area network or with another automated guided vehicle, the external device or one of automated guided vehicles stores information on start instructions for the automated guided vehicle or other information needed for running, and the automated guided vehicle refers to and timely obtains the information needed for running, which is stored in the external device or in another automated guided vehicle, by itself via the wireless local area network adapter, and running control is conducted by itself based on the obtained information.

19. A method for controlling an operation of an automated guided vehicle by passing information by radio between the automated guided vehicle for conducting a transport of articles or other work by running a designated running route and an external device connected to a local area network via a wireless local area network, the method comprising the steps of storing information needed for running including information on start instructions for the automated guided vehicle in the external device or one of a plurality of automated guided vehicles, referring to and obtaining the information needed for running, which is stored in the external device or in another automated guided vehicle, via the wireless local area network in the automated guided vehicle, and conducting running control by itself based on the obtained information.

20. The operation control method according to claim 19, the method comprising storing area entry information that controls the automated guided vehicle from entering a designated running area in an external device or an automated guided vehicle, obtaining the area entry information from the external device or another automated guided vehicle via the wireless local area network in the automated guided vehicle, confirming whether there is any other automated guided vehicle in the designated area other than itself based on the obtained area entry information, and determining whether to enter the designated area based on the result of judgement.

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L32: Entry 1 of 1 File: USPT Jan 18, 1994

DOCUMENT-IDENTIFIER: US 5280431 A
TITLE: Method for controlling the movements of a mobile robot in a multiple node factory

Brief Summary Text (9):
Systems such as those described in the related Texas Instruments applications achieve true point-to-point movement by implementing control schemes which allow multiple AGVs to coexist in the same pathways without collision or excessive queuing and by using free-roving AGVs having programmable bi-directional paths. These new methods maximize the degrees of freedom of AGV movement. The control scheme set forward in TI-11104, co-pending, implements a scheme of "static" collision avoidance for AGV systems. Essentially, that method uses a rule-based computer program to examine the "mapped environment" set forward in TI-10942, U.S. application Ser. No. 771,397 and to report only those pathways determined "passable to AGVs" to a central data base, from which another scheduling program can draw the data necessary to move AGVs from one point to another in the system without attempting to place two AGVs in the same place simultaneously.

Brief Summary Text (13):
The invention is an addition to the control scheme set forward in Texas Instruments application 10942 (U.S. Ser. No. 771,397), where an external system executive coordinates the tasks of multiple, independently running, computerized control programs which include a communications controller task, a central data base, onboard vehicle controller tasks, an AGV-routing task, an AGV-scheduling task, and a visual navigation system task to provide factory-floor position information updates to free-roving mobile robot AGVs which incorporate onboard dead reckoning. In the TI systems, the AGVs travel within programmable pathways. The AGVs are omnidirectional and can rotate in place; that is, they have a zero turning radius and can move with equal control in any direction. This scheme allows the AGVs to operate in a minimum of pathway space but simultaneously to service a factory layout with maximum efficiency. Furthermore, since the path is not physically attached to the floor, and since the external control scheme can identify the individual AGVs separately, the AGVs can pass each other in any direction, with or without stopping.

Brief Summary Text (34):
Both dynamic and static control are necessary because the various control programs in the stationary and mobile controllers can be considered "intelligent." In this case, "intelligent" means that the control programs are capable of simultaneous and independent operation, as well as dynamic determination of, and reaction to, various operating parameters. The operating system for the system executive is a real-time, multitasking program. These characteristics allow the various parts of the control system to act independently. The central data base concept adds the capability for the independent tasks to access information from other tasks. the effect is to maximize both control (through the hierarchy) and autonomy. Therefore, each independent task must be capable of controlling itself and of interacting with the distributed control system autonomously .

Detailed Description Text (2):
In the TI systems, an AGV can move from one point to any other point in more than one way. As many as six AGVs may be operating independently and simultaneously in the same area. Furthermore, although specific paths are defined (and reserved) for the AGVs, the AGVs may at times wander off-path and collide with obstructions. These characteristics make it imperative to have some means of continuously monitoring AGV location. When the AGVs move along a path, a certain amount of deviation from the path occurs. The TI systems described in the related applications comprehend and control this deviation. The control systems relate AGVs to a "factory map" which can be thought of as a list of nodes. This method of control requires two independent mechanisms:

Detailed Description Text (19):
From the viewpoint of the AGV controller, the AGV is always either idle or moving from the "oldest" point in a first-in, first-out (FIFO) buffer (where the node list is stored) to the "next oldest" point in that same buffer. Thus, it is possible to have many such lists, one for each AGV in the system, in order to control several AGVs "simultaneously."

Detailed Description Text (32):
As has been noted earlier, communication between stationary and mobile parts of the AGV system computer programs takes place in the form of coded messages. These messages include an AGV identifier to ensure that a message gets to the proper AGV. There is one and only one identifier for each AGV and no two AGVs have the same identifier. And, since it sometimes is necessary to convey a message to all AGVs simultaneously, a separate identifier in a message causes all active AGVs in the system to interpret the message.

Detailed Description Text (33):
Messages may be sent continuously from the stationary system controller to any or all AGVs in the system. FIG. 4 illustrates how the invention bridges the gap between the stationary tasks and the mobile tasks. Note, however, that the hierarchical and modular nature of the tasks allows many copies (one for each AGV in the system) of the tasks to operate simultaneously and independently while the stationary system controller retains the ability to control any or all tasks as necessary. The method by which the mobile portion of the system-level AGV control program aboard a specific AGV communicates with other parts of the system is a primary part of the invention. Essentially, system-level control tasks loop continually in the stationary controller while other AGV-level control tasks loop continually in the vehicle controller aboard the AGV.

Detailed Description Text (59):
It is important to note again that the external system executive operates in a multitasking operating system. This makes it possible to run many copies of the invention simultaneously and independently. In actual implementations to date, as many as six copies of the invention run simultaneously per system. The hierarchical organization of these tasks makes possible the maximum AGV autonomy for a given level of system executive control.

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L14: Entry 1 of 2 File: USPT Sep 28, 2004

DOCUMENT-IDENTIFIER: US 6799099 B2
TITLE: Material handling systems with high frequency radio location devices

Abstract Text (1):
A material handling system uses high-frequency location devices for determining the location of mobile units, such as AGVs, overhead mono-rails, conveyor components, or individual articles being transported by such units. The high-frequency location devices may also be used to identify the contents and/or routing information for material being moved within a facility. AGVs may incorporate the high-frequency location devices into their navigation systems to utilize the position and/or heading updates provided by the location devices in guiding the vehicle. The location devices work in cooperation with a number of stationary location devices, such as beacons, that are positioned within the environment at known locations, such as in or adjacent the ceiling of the workplace environment. High-frequency radars may also be used to provide electronic bumpers to the AGVs, allowing them to sense obstacles and take appropriate action to avoid collisions with the obstacles.

Application Filing Date (1):
20020731

Parent Case Text (2):
This application claims priority to commonly-assigned U.S. provisional applications No. 60/309,568 entitled Ultra-Wideband AGV System, filed Aug. 2, 2001, and No. 60/318,029, entitled Ultra-Wideband Material Handling System, filed Sep. 10, 2001, the disclosures of which are both hereby incorporated herein by reference.

Brief Summary Text (3):
Automatic guided vehicles, or AGVs for short, are used extensively today in a wide variety of material handling applications. AGVs come in a wide variety of types, from those that carry cargo on their back, to those that tow trains of cargo behind them on carts, to still other types. In order for each AGV to be able to automatically guide itself throughout a factory or plant, it must be able to determine its position within the factory. In the past, the determination of the vehicle's position has been carried out in several different ways. Some AGVs use laser targets positioned at known locations throughout the factory to reflect a laser beam emitted from the AGV. The reflection of the laser beams are detected by the AGV and used to determine the position of the AGV relative to the targets. Using three or more targets, the vehicle can then calculate its position. An example of such a prior art AGV system is disclosed in U.S. Pat. No. 4,790,402 issued to Field et al., the disclosure of which is hereby incorporated herein by reference.

Brief Summary Text (4):
In another type of AGV, the vehicle uses a combination of incremental sensors and one or more beacon sensors to determine its position. The incremental sensors detect changes in the vehicle's position or bearing, while the beacon sensors make absolute measurements of the vehicle's position or heading with respect to one or more fixed beacons positioned throughout the factory. By combining the use of both

incremental and beacon sensors, the vehicle is able to determine its position and/or heading sufficiently often and with sufficient accuracy to guide itself to its intended destination. Examples of incremental sensors used on AGVs include wheel encoders that measure the rotations of one or more wheels on the AGV, and gyroscopes that measure changes in the vehicle's orientation. Examples of beacons include magnets buried in the floor, transponders positioned at known locations, laser targets such as those described above, and various other detectable marks or objects. One prior art AGV system that uses wheel encoders, a gyro, and magnets positioned in the floor for navigation is disclosed in U.S. Pat. No. 5,281,901 issued to Yardley et al., the disclosure of which is hereby incorporated herein by reference.

Brief Summary Text (5):
In the past, the various types of AGV systems have each suffered from certain disadvantages. In virtually all of the prior AGV systems, the measurement of the position of the beacons during their installation--whether they are magnets, transponders, reflectors, or other types--has often been a labor-intensive and expensive task. In addition, with respect to the laser-reflector AGVs, these systems require a visual line-of-sight between the vehicle and the target which can often be difficult to obtain in a crowded factory or plant environment. The use of magnets or transponders buried in the floor requires drilling or other operations that can be disruptive to the operation of the factory, and which can have significant costs. Further, the magnets or transponders must be placed on or adjacent to the vehicle pathways in order for the vehicle to be able to detect them. Changes in the pathway therefore often require the installation of additional magnets.

Brief Summary Text (6):
In addition to the foregoing disadvantages of the various navigation systems, prior art AGV systems have also had certain disadvantages in their communications systems. For example, some prior art AGV systems rely on a central controller or repeater that issues or repeats communications received from vehicles. In such systems, the vehicles do not directly contact each other, but instead channel their messages to the central controller or repeater. If a communications failure occurs with the central controller or repeater, then the whole communications system fails. Such single point of failure communication systems are desirably avoided, if possible. Additionally, prior art AGV systems have often used RF communications which are susceptible to interference, especially in plants that have extensive metal structures and electrical/electronic equipment that may emit its own radiation. These problems are also desirably avoided. The need can therefore be seen for an AGV system which overcomes the aforementioned disadvantages.

Brief Summary Text (7):
Prior AGVs have also typically included one or more bumpers on their front and/or back ends that allow the vehicle to safely stop or slow down when objects in its path are detected. Such bumpers may consist of a physical structure that produces an electric signal when impacted, optical sensors that optically detect obstacles in the vehicle's path, laser sensors that detect laser signals emitted from the vehicle and reflected off of obstacles, or combinations of these various types of sensors. One such system is described in more detail in U.S. Pat. No. 5,048,637 issued to Lomasney. While such systems have proven to be adequate, they are often expensive to implement. Furthermore, their detection range for detecting obstacles is often limited such that it is possible for small objects to escape detection by the sensor and possibly cause damage to the vehicle, the undetected object, or both. More inexpensive sensors with a broader field of vision are therefore desirable.

Brief Summary Text (8):
In addition to the use of AGVs to move material between different locations within a warehouse, conveyors and other types of material handling equipment are often

used. In order to ensure that the materials are properly moved to their intended destination, they often include a bar code on one of their sides. These bar codes are read by a scanner which is in communication with the appropriate control circuitry to ensure that, after reading the bar code, the material handling system will deliver the article to its intended destination. In order for the bar code scanner to work properly, it is often necessary to make sure that all of the articles are properly oriented so that their bar codes can be read by the scanner. Further, it is often necessary to re-scan articles whose bar codes have become covered in dirt, wrinkled, or otherwise unreadable. A method of tagging articles such that these and other difficulties could be overcome is also desirable.

Brief Summary Text (15):
According to another aspect of the present invention, a method is provided for installing an AGV system within an environment. The method includes providing a plurality of electromagnetic energy emitting beacons and at least one automatic guided vehicle that includes at least one sensor for detecting transmissions from the plurality of beacons. At least three of the beacons are placed within the environment in a roughly triangular geometry and the location of the beacons are measured. Thereafter, additional beacons are placed in the environment and the measured beacons are used to determine the location of the additional beacons within the environment. The position of the additional beacons is communicated to the automatic guided vehicle.

Brief Summary Text (20):
The AGVs, communications systems, navigation systems, and other aspects of the present invention provide various improved features for material handling systems. Among these improved features are reduced costs, better control of material movement, easier installation of material handling systems, such as AGV systems, improved communications ability, more flexible usage of material handling equipment, and increased safety. These and other benefits of the present invention will become apparent to one skilled in the art in view of the following description when read in conjunction with the accompanying drawings.

Drawing Description Text (2):
FIG. 1 is a side, elevational view of one embodiment of an AGV to which the present invention finds application;

Drawing Description Text (3):
FIG. 2 is a plan, schematic view of selected components of the AGV of FIG. 1;

Drawing Description Text (4):
FIG. 3 is a perspective view of an AGV system according to one embodiment of the present invention;

Drawing Description Text (5):
FIG. 4 is a schematic view of an AGV and a plurality of beacons, illustrating a first method by which the AGV determines its position and/or heading;

Drawing Description Text (6):
FIG. 5 is a schematic view of an AGV and a plurality of beacons, illustrating a second method by which the AGV determines its position and/or heading;

Detailed Description Text (2):
The present invention will now be described with reference to the accompanying drawings wherein like reference numerals correspond to like elements in the several drawings. An illustrative example of a material handling system, which may be in the form of an automatic guided vehicle (AGV) 20, to which the present invention can be applied is depicted in FIG. 1. AGV 20 may be the type of vehicle which is described in more detail in U.S. Pat. No. 5,764,014 issued to Jakeway, the disclosure of which is hereby incorporated herein by reference. AGV 20 includes a

plurality of drive wheels 22 which are powered by motors 23 (FIG. 2) and drive the vehicle 20. AGV 20 further includes a front, steerable wheel 24, a hitch 26 for towing trailers of material, a mechanical front bumper 28, a battery storage compartment 30 for storing the batteries that provide power to the drive wheels 22, and a local operator console 32 that allows the vehicle to be operated manually by a user. When local operator console 32 is not in use, AGV 20 guides itself automatically from destination to destination. AGV 20 may also include a ground track sensor 34 that provides navigation information to the vehicle in a manner described more fully in U.S. Pat. No. 5,764,014, and an ultra-wideband radar bumper 36 that will be described in more detail herein. It will, of course, be understood that the present invention finds equal application to other types of AGVs and that AGV 20 is only one example of the many different types of AGVs to which the present invention may be applied.

Detailed Description Text (3):
AGV 20 includes a navigation system 38 that is illustrated in block diagram form in FIG. 2. The navigation system 38 includes ground track sensor 34, a heading reference sensor 40, a distance measuring encoder 42, an angle encoder 44, and a high frequency radio transceiver 46. The operation of ground track sensor 34, heading reference sensor 40, distance measuring encoder 42, and angle encoder 44 is described in more detail in U.S. Pat. No. 5,764,014. Suffice it to say that ground track sensor 34 measures the rotation and angular position of a unloaded ground wheel 48. This information is fed to a navigation computer 50 which uses the information, in conjunction with other navigation information, to determine the vehicle's location and heading. Navigation computer 50 outputs commands to a steer board to steer front wheel 24 to cause the vehicle to stay on an intended path. Angle encoder 44 measures the angular orientation of a caster wheel assembly on which front, steerable wheel 24 is mounted. This angular information is also fed into navigation computer 50. Distance measuring encoder 42 measures the number of rotations of front wheel 24 and feeds this information to navigation computer 50 for use in determining the vehicle's position and heading. Heading reference sensor 70 provides information about the heading of the vehicle to navigation computer 50, and may include a gyroscope.

Detailed Description Text (4):
The gyroscope, angle and distance encoders, and ground track sensor may all be incremental sensors. That is, they may not, by themselves, be able to determine an absolute position or heading of the vehicle within a given frame of reference, but instead may only be able to sense changes in position and heading. In order to determine an absolute heading or position of the vehicle 20 within a given frame of reference, high-frequency radio transceiver 46 is provided. Transceiver 46 may be a device that sends and receives high-frequency radio signals, such as ultra-wideband signals, or other signals. Transceiver 46 may have multiple antennae placed at various points on the vehicle, allowing measurement of relative angles. These signals are used to determine the vehicle's absolute position and/or heading in a given frame of reference. In the illustrated navigation system, the absolute heading and/or position information provided by transceiver 46 to navigation computer 50 merely supplements that provided by the other navigation sensors. In this embodiment, transceiver 46 therefore does not need to provide position and heading information updates as quickly as it would if some or all of the other navigation sensors were removed. It will be understood by one skilled in the art that some or all of the other navigation sensors on vehicle 20 can be removed by simply increasing the rate at which transceiver 46 receives accurate position and heading measurement information. For example, if transceiver 46 provides updated heading information as quickly and accurately as the gyroscope in heading reference sensor 40, then heading reference sensor 40 could be discarded. Therefore, navigation system 38 may or may not include sensors other than transceiver 46. The operation of transceiver 46 will be described in more detail below.

Detailed Description Text (5):

An illustrative example of an AGV system 52 is depicted in FIG. 3. The AGV system 52 includes at least one AGV, such as AGV 20, which travels on a floor 55 throughout a plant or factory and which is adapted to carry loads. The loads may be carried on the top of the AGV, on one or more carts towed behind the AGV, or in any other manner. The AGV is able to steer itself automatically from one location to another based on instructions received from an off-board controller or from a person who manually enters an intended destination into an interface on the vehicle. As discussed above, AGV 20 includes one or more incremental navigation sensors on-board which the vehicle uses to help determine its position and/or heading. The types and number of incremental sensors are not limited within the scope of the present invention, but include such sensors as gyroscopes, wheel encoders, potentiometers, and others. Other low grade position sensors, such as flux gate compasses or magnet position sensors may also be employed. In addition to the one or more incremental and position navigation sensors, AGV 20 includes at least one transceiver 46 adapted to detect one or more stationary beacons 54 positioned at known locations throughout an environment. In the example of FIG. 3, beacons 54 are positioned along a ceiling 56. Beacons 54 could alternatively be placed at any other locations that are within range of detection by AGV 20, as will be explained in more detail below.

Detailed Description Text (6):
AGV 20 uses one or more of beacons 54 to periodically determine its position and/or heading. While AGV 20 receives information about its location and heading from the one or more incremental sensors it has on-board, these incremental sensors have to be initialized and also tend to produce errors that increase over time. Beacons 54 provide sufficient information to AGV 20 to allow itself to both initially determine its position, and to update its position and/or heading periodically as it travels throughout the plant. AGV 20 detects the one or more beacons 54 by way of one or more transceivers 46 positioned on-board vehicle 20. (FIG. 2). In one embodiment of the present invention, beacons 54 may be various types of high frequency radio location devices such as the ultra-wideband transceivers disclosed in U.S. Pat. No. 6,054,950, issued to Fontana, the disclosure of which is hereby incorporated herein by reference. Transceivers 46 on-board the vehicle may be ultra-wideband receivers/processors, such as those disclosed in U.S. Pat. No. 6,054,950. In another embodiment of the present invention, beacons 54 are FMCW devices, such as those disclosed in U.S. Pat. Nos. 6,255,984 issued to Kreppold, et al. and 6,278,398 issued to Vossiek, et al., the disclosures of which are both hereby incorporated herein by reference. Any other types of high frequency location devices that fall within the 3-6 Gigahertz range, which was recently approved for ultra-wideband uses in the United States by the U.S. Federal Communications Commission, could also be used, although frequencies outside this range may also be used. Still other types of high frequency location devices may also be used, such as frequency modulated radar systems and the like.

Detailed Description Text (7):
Beacons 54 are installed at known locations throughout an environment in which one or more AGVs 20 are to operate. The location of beacons 54 is communicated to each of the AGVs 20 in any known manner, such as by wireless transmission, manual entry, downloading, or by any other means. Each AGV 20 uses signals transmitted between one or more beacons 54 and the transceiver(s) 46 it has on-board to determine its position and/or heading. An example of the manner in which the AGV is able to determine its position from the beacons 54 is depicted in FIG. 4. Each beacon 54 emits a short, electromagnetic pulse that is detected by the one or more transceivers 46 located on AGV 20. By determining the time of flight for the emitted pulse to travel from one beacon 54 to a transceiver 46, AGV 20 is able to calculate the distance between the beacon 54 which emitted the pulse and the transceiver 46 which detected the pulse. By determining the transceiver's distance to three or more beacons 54, the vehicle is able to determine its position within the facility.

Detailed Description Text (8):
For example, if beacon 54a in FIG. 4 emits a pulse that takes 5 nanoseconds to travel to transceiver 46a, then a distance 31a between transceiver 46a and beacon 54a can be computed by multiplying the propagation speed of the pulse by the time-of-flight. If the propagation speed is taken to be 300,000,000 meters/second, then the distance 31a is 1.5 meters (300,000,000 m/s times 0.000000005 s). It is therefore known that transceiver 46a lies somewhere on a sphere having a radius of 1.5 meters centered at beacon 54a. In order to further pinpoint the location of transceiver 46a within the facility, additional distance measurements can be taken from other beacons, such as distances 31b and 31c, which correspond to the distances to beacons 54b and 54c (FIG. 4). Taking such measurements from at least three beacons should provide sufficient information for AGV 20 to be able to calculate its position within the facility, as would be understood by one skilled in the art. Such calculations can take place by any conventional means, such as by using one or more microprocessors, or by other means. In the illustrated embodiment, navigation computer 50 may be programmed to carry out these calculations. Alternatively, a separate processor associated directly with transceiver(s) 46 can perform these calculations and communicate the result to navigation computer 50. The details by which transceiver 46 determine their position from beacons 54, in one embodiment, are described more fully in U.S. Pat. No. 6,054,950.

Detailed Description Text (9):
In order to improve the accuracy of the measurement of the distance between vehicle 20 and beacon 54a, AGV 20 may include a plurality of transceivers 46 arranged in an array of known configurations. The distances of each transceiver 46 to beacon 54a can first be determined and then combined together, such as by averaging or other methods, to produce an estimate of vehicle position relative to beacon 54a with greater accuracy. For example, if each transceiver 46a-d in FIG. 4 measures it position away from beacon 54a by determining the time of flight of a pulse emitted from beacon 54a, these four distance determinations can be combined to produce a better estimate of the vehicle's distance from beacon 54a, provided the location of each of the transceivers on-board the vehicle is known. After making a measurement of the vehicle's distance from beacon 54a, vehicle 20 can proceed to make additional distance measurements from other beacons 54 in a like manner and use these distance measurements to determine its position. As would be understood by one skilled in the art, the multiple measurements of vehicle distance should be made simultaneously, or nearly simultaneously, before they are combined together in order to avoid the need for accounting for possible movement of the vehicle between distance measurements. If the measurements are not made nearly simultaneously, such movement can be accounted for prior to combining the multiple measurements by way of the other navigation sensors, or by other methods, as would be understood by one skilled in the art.

Detailed Description Text (10):
In addition to determining the position of AGV 20, beacons 54 and transceivers 46 can be used to calculate the vehicle's heading. Such heading calculations can be accomplished, in one embodiment, by determining the location within the facility of two transceivers 46 on-board AGV 20. Provided the orientation of the vehicle transceivers with respect to the vehicle is known, the heading of the vehicle can be calculated. For example, suppose transceivers 46a and 46b are mounted to a vehicle such that a line drawn between the two transceivers points in the direction considered to be the heading of the vehicle 20. Suppose further that the vehicle determines the position of transceiver 46a within a facility to be (x.sub.a, y.sub.a), and the position of transceiver 46b to be (x.sub.b, y.sub.b), where the letters x and y refer to the two-axes of a coordinate frame of reference. The vehicle can compute its heading within this frame of reference according to the following formula:

Detailed Description Text (15):

The time it takes for signals detected by transceiver(s) 46 to be processed should be known. One manner of doing this involves knowing the physical distance between each transceiver and a processor that processes the detected signals so that the time it takes for signals to travel along the one or more wires to the processor can be accounted for. Alternatively, each transceiver 46 may be programmed to time-stamp each signal it detects from a beacon 54. The time stamp can be used to ensure that accurate measurements of flight times or arrival times are made. If multiple transceivers 46 are on-board a vehicle, such it is important to ensure that such time stamping each transceiver 46 is synchronized with the other transceivers. Such synchronization can be carried out using a synchronization pulse, or by other means. The on-board synchronization can be further enhanced by using interferometric methods. Such interferometric methods can significantly increase the precision of the synchronization of the transceivers, thereby increasing the precision by which the differences in arrival times are measured, which in turn increases the accuracy of the vehicle's position and/or heading measurement.

Detailed Description Text (16):
As an alternative to the above-described methods for determining the heading and position of AGV 20, the heading and position of the vehicle can be determined without calculating the flight times of signals emitted from beacons 54. In such an alternative embodiment, the position and heading of the vehicle 20 is determined by comparing the differences in time in which one or more signals from a beacon 54 are detected by three or more transceiver antennae 46 positioned on the vehicle at known locations. This method is illustrated in FIG. 5. By using this method, it is not necessary to know precisely when a signal was emitted from a beacon 54. For example, suppose beacon 54b in FIG. 5 emits a signal. This signal will travel a distance 33a before it reaches, and is detected by, transceiver 46a. Likewise, the signal will travel distances 33b-d before it reaches, and is detected by, transceivers 46b-d, respectively. Because the distances 33a-d are different from each other, the time at which transceivers 46a-d will detect the emitted signal will be different from each other. By comparing the relative times at which the signal is detected by the different transceivers, the position of the vehicle with respect to beacon 54b can be determined. This is true regardless of whether the time of detection of the signal at each of the transceivers 46a-d is different or simultaneous. Of course, it is necessary to know the relative positions of transceivers 46a-d with respect to each other on the vehicle.

Detailed Description Text (20):
The different methods for determining the vehicle's position and heading are summarized in flowcharts in FIGS. 6 and 7. In a first method 57 for determining the vehicle's position and reading illustrated in FIG. 6, one or more pulses are emitted at a step 58. The pulses may be emitted from a transceiver 46 aboard the vehicle, or they may be emitted from a beacon 54. At step 60, the time of flight of the emitted pulse to a first sensor is determined. The reference to a sensor in FIGS. 6 and 7 refers to transceiver 46 if the emitted signal came from a beacon 54, or to a beacon 54 if the emitted pulse came from transceiver 46. It will be understood by those skilled in the art that the present invention finds equal application to those systems in which times of flight or arrival times are measured based on signals emitted from the vehicle to the beacons, or vice versa. At step 60a, the time of flight of the emitted signal to a second sensor is determined. At step 60c, the time of flight of the emitted signal to another sensor is determined (the N.sup.th sensor). The total number of sensors used to measure time of flights is represented by the variable N, and N may be any integer greater than or equal to one. Steps 60b and c therefore may be optional in some embodiments. After all of the time of flight measurements have been made, the distances from the pulse emitter to each pulse sensor is determined at step 62. The distance information is used to determine a positional relationship between the emitter and at least one sensor at step 64. The positional relationship may be an absolute measurement of the vehicle's position within a facility, or only a relative measurement of the vehicle's position to one or more beacons 54, depending on the number of time of

flight measurements used. After step 64, method 57 may include an optional step 66 in which multiple positional relationships between the emitter and multiple sensors are combined into a single positional relationship. This optional step may be used when multiple sensors are present. By combining the positional relationship from multiple sensors into a single measurement, which may be done by averaging, a least square method, or other means, a more accurate positional relationship may be generated. The measurements are combining based upon the knowledge of the physical location of each of the sensors relative to each other. At another optional step 68, the heading of the vehicle may be determined based upon multiple position determinations from either step 64 or step 66. Optional step 68 is implemented after method 57 has cycled through steps 58-64 a sufficient number of times to provide sufficient position information by which the heading of the vehicle can be determined.

Detailed Description Text (23):
The use of beacons 54 and transceivers 46 for the navigation of AGV 20 can be augmented by using one or more incremental sensors, as noted above. Such incremental sensors are particularly desirable if beacons 54 and transceivers 46 do not provide fresh measurements of position or heading with sufficient frequency to properly guide the vehicle. The measurements of heading and/or position obtained from beacons 54 and transceivers 46 can be combined with the position and heading information from the one or more incremental sensors to produce a more accurate estimate of the vehicle's heading and/or position. The combination of the incremental sensor information and the beacon/sensor information can be accomplished in any conventional manner, including through the use of a Kalman filter. A Kalman filter can be used with any of the methods for determining heading or position described above.

Detailed Description Text (24):
Navigation system 38 utilizes beacons 54, transceiver(s) 46, and one or more processors, either separate from or part of navigation computer 50, for combining and processing the signals received by transceivers 46. The navigation system can be used either alone or in combination with other navigation sensors, such as the incremental sensors described above. If used in combination with other incremental sensors, the navigation system can be installed on original vehicles, or it can be added to existing AGVs. For example, the navigation system of the present invention could be installed as a retrofit kit on pre-existing vehicles, such as, for example, those described in U.S. Pat. No. 5,280,901. Such vehicles use a gyroscope, wheel encoders, and a magnet sensor that detects magnets positioned at known locations on the floor of a plant to navigate. By installing the navigation system of the present invention on such a vehicle, one or more of the gyroscope wheel encoders and magnet sensors can be removed and replaced with the beacon/transceiver system of the present invention, which would provide the same or comparable navigation as the removed sensor or sensors. A navigation kit according to the present invention provides periodic updates of the vehicle's position and heading that allow it to replace one or more of these sensors. The navigation system of the present invention could therefore replace the magnet sensors of the vehicles disclosed in the '901 patent. Instead of using magnets for periodic updates, the vehicle would use the beacons and sensors for periodic updates of position and heading. Because the magnets have to be positioned on or adjacent to the AGV's pathway, and the beacons 54 do not, such a replacement would allow the vehicle's pathways to be easily changed without having to relocate magnets or beacons. The navigation system of the present invention could also eliminate the need for the gyroscope and one or more of the wheel encoders. The navigation kit of the present invention could also be used to replace one or more navigation sensors on other types of vehicle's, such as those that use laser reflectors or those that use transponders buried in the floor, as well as other types.

Detailed Description Text (25):
The installation of AGV system 52 can be easily accomplished. Beacons 54 are

mounted in any known manner at locations throughout the facility, such as on a ceiling, on the tops of racks or other stationary structures, in the floor, or in still other locations. Once one or more of these beacons have been installed, the position of at least three beacons are determined by surveying or other means. After the location of these first beacons are determined, the position of the other beacons can be determined in a variety of manners using common surveying techniques for measurement of beacon relative locations and subsequent error reducing analytical algorithms. The need to physically survey every single beacon in the facility during installation can therefore be avoided. In order for the beacons to be able to determine their positions with respect to each other, it is necessary for them to be able to both transmit and receive signals, i.e. to be transceivers. Transceivers that can be used for this purpose are described in the U.S. Pat. No. 6,054,950 patent.

Detailed Description Text (26):
It will be understood that the foregoing description of the use of one or more transceiver 46 on board AGV 20 does imply that only transceivers can be used on board vehicle 20 in accordance with the present invention. For example, in situations in which beacons 54 emit signals detected by transceivers 46 and used to determined the vehicle's position and/or heading, transceivers 46 could simply be receivers. Alternatively, in situations in which transceivers 46 were used to emit signals detected by beacons 54, transceivers 46 could simply be transmitters. Likewise, beacons 54 could be either transmitters or receivers in these different situations. The term "beacon" as used in this application is therefore intended to cover receivers, transmitters, and transceivers.

Detailed Description Text (27):
In addition to using ultra-wideband signals for determining the location and/or heading of AGV, ultra-wideband signals can be used for communication in material handling systems, such as AGV system 52. Using previously disclosed embodiments as an example, each AGV includes an ultra-wideband transceiver that may or may not be the same as a transceiver 46. The communication can be directly between vehicles, between each vehicle and a central station, or some combination thereof. The communications can include any type of information, such as destination information, load information, blocking information, or other information. By using ultra-wideband signals for communication, the communications can be more secure from interference. Such communication could be accomplished by transmissions during the intervals between navigation signals from the beacons, or the navigation signals from the beacons could themselves be sent with a certain order and/or frequency that defined one or more messages. The ultra-wideband communications could also be implemented on AGVs that did not use ultra-wideband navigation techniques.

Detailed Description Text (28):
High frequency radio transmitters, such as ultra-wideband transmitters, can also be placed on or adjacent to loads to be picked up by an AGV. Such transmitters may broadcast one or more messages indicating that a load is to be transported, the contents of the load, the destination of the load, or other information concerning the load. The initiation of such signals can be implemented by a worker pressing a button on the transmitter, or by taking other steps to cause the transmitter to transmit such a message. The transmitter may also broadcast its location, or signals sufficient for the AGVs to determine its location. Each AGV may include a controller for determining which of the available AGVs should respond to the message, or a central controller may dictate which AGV should respond to the message. Such transmitters allow loads to be monitored by a central control system throughout their movement in the facility. The transmitters may also respond to a centralized request for information in order to allow automatic inventories to be taken of material in a facility.

Detailed Description Text (29):

Beacons 54 could also be placed on individual AGVs, other mobile vehicles in the facility--such as driver-guided fork-lift trucks--or on stationary objects, in order to avoid collisions with these objects. By being able to determine its location with respect to beacons 54, vehicles 20 steer themselves accordingly to avoid collisions with certain designated beacons, such as those on fork-lift trucks or at other occupied locations. When vehicle 20 detects that it is within a certain vicinity of a beacon 54 that it should avoid, such as one on a fork-lift truck, a controller on vehicle 20 implements an appropriate velocity change to help avoid a collision with the fork-lift truck. In this manner, plant safety can be improved while minimizing the costs associated with collisions.

Detailed Description Text (30):
According to another aspect of the present invention, AGV 20 includes a high frequency radio radar module or bumper 36 located at a position on the vehicle that enables it to detect nearby objects (FIG. 1). The high frequency radio radar can be any conventional module, such as the ultra-wideband radar modules disclosed in U.S. Pat. No. 5,805,110 issued to McEwan, the disclosure of which is hereby incorporated herein by reference. Alternatively, the radar bumper could comprise a phased array of high frequency radio antennas 82 (FIG. 8). A high frequency pulse is emitted from one of the individual antennas 84 and it reflects off of an object 86 back to the array 82. The antennas 84 detect the reflected signal at different times based upon the location of object 86. A processor compares these different detection times to determined the position of the object in a manner that would be known to one skilled in the art. While radar bumper 36 is depicted as a single bumper on the front of vehicle 20 in FIG. 1, it will be understood that multiple radar bumpers could be incorporated onto a vehicle, such as at the back of the vehicle, which is particularly useful for vehicles that are capable of bi-directional travel. For vehicles capable of side-to-side movement, additional radar bumpers 36 could be placed on the sides of the vehicle to determine whether obstacles are blocking the vehicle's side-to-side movement. The detectable range of the radar bumpers 36 can be set to any desirable distance, but would preferably be very close to the vehicle for side bumpers 36, in front of mechanical bumper 28 for the front bumper 36, and close to the back end of the vehicle for rear bumper 36. Object detection range can also be controllable during operation to allow a safety zone tailored to the vehicle's current task. The detected information from bumper 36 could be forwarded to navigation computer 50, which would issue any appropriate steering commands to make in light of the detected object.

Detailed Description Text (31):
The high frequency radio radar module 36 can be used for a variety of purposes. The radar can be used to detect objects that obstruct the path of the vehicle, such as other vehicles, fork-lift trucks, pallets, personnel, or any other objects that might get in the way of a vehicle's path. In such situations, AGV 20 may be programmed to either stop and wait until the obstruction is removed, or to follow an alternate route to avoid the obstacle. Alternatively, the radar can be used for accurately stopping the vehicle at transfer stations, battery recharging stations, or any other locations where the vehicle must be accurately positioned. When accurately stopping at a station, the radar indicates to the vehicle its distance from a reference structure at or near the station. The vehicle stops itself at a predetermined location with respect to the reference structure. The reference structure can be any structure which is detectable by high frequency radio radar, including structures that exist within the facility prior to the AGV installation, or structures that are specifically added to provide references for the AGVs. The reference structures may be different for different stations, and AGV 20 is programmed to store the appropriate data concerning the reference structure for each station.

Detailed Description Text (32):
The high frequency radio radar module can also be used for picking up loads that are not oriented at pre-determined orientations, such as loads that are deposited

on the floor or other structure from a fork-lift truck. If AGV 20 is equipped with a fork-lifting capability, the high frequency radio radar module can be positioned to detect the orientation of the pallet. Based on the detected orientation of the pallet, AGV 20 steers itself appropriately to insert its fork-lift prongs into the pallet, pick it up, and transport it to an intended destination. The various uses for the high frequency radio radar module described above are not mutually exclusive, but rather a single AGV can use one or more radar modules to perform each of the functions described above, as well as other functions.

Detailed Description Text (33):
According to still another aspect of the present invention, beacons 54 and transceivers 46 can be used as a position monitoring system for monitoring the position of AGVs, manned vehicles, such as fork-lift trucks, material loads, or a mix of these items. Such monitoring systems can be used independently of any navigation functions provided by beacons 54 and transceivers 46, or they can be used in combination with such navigational functions. For example, a plurality of beacons 54 can be positioned at known locations throughout an environment and one or more transceivers 46 can be positioned on-board the vehicle(s) and/or loads, or vice versa. The vehicle may be either an AGV, a manned vehicle, or some other type of mobile unit. The load may be a fork-lift pallet, a carton, an individual package, or some other material unit whose position may change in the facility. The position of the load and/or the vehicle is determined in accordance with one of the methods previously described. The heading of the vehicle can also be determined in accordance with one of the methods previously described.

Detailed Description Text (37):
UWB transceivers, such as transceivers 46, can also be used in other material handling applications outside AGVs. Such transceivers can be incorporated into components of material handling systems for automatic identification and configuration of components of the material handling system. For example, in sortation systems for conveyors, there may be a number of individual divert control modules 100 associated with each branch conveyor 96 on a given sortation conveyor 92 (FIG. 10). The control modules 100 control, by way of example, the mechanisms for positively displacing articles 90 off of the sortation conveyor onto an adjacent branch conveyor 96. The precise number and location of each of the sortation modules 100 may vary according to the particular installation. During the installation of the sortation system, it is often necessary for a higher level controller of the overall sortation system, such as divert controller 94, to know the position of each of the control modules 100 so that the higher level controller 94 can send divert signals to the correct control module 100 when a particular article 90 is to be diverted to a particular branch conveyor 96. This is discussed in further detail in commonly assigned, U.S. patent application Ser. No. 10/163,788, filed Jun. 6, 2002, and entitled Tiered Control Architecture For Material Handling, the disclosure of which is hereby incorporated herein by reference. In the past, the physical location of such divert control modules 100 was manually input into the higher level controller 94 during installation of the sortation system. By placing transceivers 46 in each divert control module, the distance of each control module down the length of the sortation conveyor can automatically be determined. Such distances are determined in any one of the manners previously described herein, and can be determined in conjunction with a transceiver 46 placed at a reference location, such as the upstream end of the sortation conveyor 92. The transceivers 46 can also be used as wireless communication devices. The higher level controller is also provided with a UWB transceiver that communicates wirelessly with the UWB transceivers 46. The communications can include commands from the higher level controller to the divert modules, status requests, feedback from the modules to the controller, and other sorts of information. The use of such wireless communications eliminates the need for hard wiring connections, such as communications bus 102, between the higher level controller 96 and each divert control module 100.

Current US Original Classification (1):
701/23

CLAIMS:

32. A method of installing an AGV system comprising: providing a plurality of electromagnetic energy emitting beacons; providing at least one automatic guided vehicle that includes at least one sensor for detecting transmissions from said plurality of beacons; placing at least three of said beacons at known locations within an environment; measuring the location of the at least three beacons within the environment; placing additional ones of the beacons within the environment; using the at least three beacons to measure the location of said additional ones of said beacons within the environment; and communicating the location of said plurality of beacons to said automatic guided vehicle via a wireless transmission; and programming said at least one automatic guided vehicle to travel along a first pathway.

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L6: Entry 15 of 30 File: USPT Jun 9, 1998

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**** See image for Certificate of Correction ****
TITLE: Automated guided vehicle having ground track sensor

Brief Summary Text (2):
This invention relates to automated guided vehicles and, in particular, to a navigation and control system for guiding an automatic guided vehicle (AGV) along a system guide path. The invention is particularly adapted for use with dead-reckoning navigation systems, but may also be utilized with systems in which the AGV follows a guide wire that is planted in the floor along the guide path. The invention finds application in material handing, such as movement of material within a factory, as well as on-road and off-road vehicles.

Brief Summary Text (3):
Automated guided vehicles have become extremely effective at movement of materials between processes in a manufacturing plant. Each of a plurality of AGVs automatically carries loads from a pickup point to a discharge point along a system guide path under the supervision of a system controller. The AGVs move along the system guide path, including choosing between branches at each branch point, while avoiding collisions with other AGVs utilizing various control techniques. Navigation of the AGV is typically either by reference to fixed guides, such as guide wires positioned in the floor along the guide path, or by dead-reckoning. Dead-reckoning systems utilize sensors within the AGV in order to monitor the heading, rate-of-change of heading, and distance travelled by the AGV along its longitudinal axis, which is controlled to coincide with the guide path. The dead-reckoning systems are advantageous because they avoid the enormous expense of placing guide wires in the floor along the entire guide path. Additionally, such dead-reckoning systems are flexible because the guide path layout may be altered by programming changes in the controls rather than requiring tearing up and repositioning of the guide wires.

Brief Summary Text (4):
Dead-reckoning systems rely upon an integration of the rate of turn of the vehicle and the distance travelled to maintain position information of the vehicle. Because such measurements tend to drift with time, it is known to supplement the dead-reckoning navigation system with a location verification system, such as markers positioned at precise locations along the system guide path. These sensors are sensed by the AGV as the AGV moves along the guide path in order to verify, and compensate if necessary, the position of the AGV.

Brief Summary Text (5):
One of the attributes of an AGV is its ability to carry enormous loads without an operator for each vehicle. In some applications, the entire load is borne by the AGV itself. In other applications, the AGV pulls, or tugs, one or more trailers which carry the load. As a loaded vehicle moves along the guide path, especially around comers, there is a tendency for the vehicle to be forced off of the guide path by the inertia of the load. Additionally, the load asserts a draft effect on the vehicle. These effects are especially troublesome, although not exclusively limited, to tugger AGVs pulling one or more trailers. This problem becomes

especially acute when the AGV traverses a floor which is uneven and has a constantly changing floor surface, such as one that has portions which vary from concrete to oily wood to steel plates, over wide expansion joints, and the like. The problem is further aggravated when the floor is covered with friction-reducing films, such as processing oils, soapy water, and the like. The slippage of an AGV may not be sensed by the vehicle primary navigation system. If the primary navigation system is a dead-reckoning system, the slippage of the vehicle may not be adequately sensed in the rate of turn sensing mechanism. Because the location verification markers are infrequently spaced along the guide path and because of the abrupt alteration of the vehicle position resulting from such slippage, the location verification system may be unable to adequately compensate for the vehicle slippage. If the primary navigation system is based upon sensing a guide wire in the floor, the presence of a pool of liquid, which may give rise to the slippage, may also interfere with adequate sensing of the guide wire.

Brief Summary Text (7):
The present invention provides an adjunct to the primary navigation system of an AGV by providing an input to the navigation and control computer of the AGV in order to more accurately determine the actual path of movement of the AGV. Such adjunct responds to slippage of the vehicle and, thereby, corrects for errors induced by such slippage and undetected by the primary navigation system. This is accomplished, according to the invention, by providing a ground track sensor which senses relative movement of the AGV with respect to the floor surface being traversed. The invention is based upon a recognition that the primary source of slippage is side-slippage of the vehicle which is not adequately detected by primary navigation systems, especially of the dead-reckoning type.

Brief Summary Text (8):
According to an aspect of the invention, an automatic guided vehicle navigation and control system includes a primary navigation system which senses a heading, or rate-of-change of heading, of an automatic guided vehicle, a ground track sensor, which senses relative movement of the automatic vehicle with respect to a surface being traversed by the vehicle, and a navigation and control computer. The navigation and control computer is responsive to the primary navigation sensing system and to the ground track sensor for determining an actual path of movement of the automatic guided vehicle. The navigation and control computer also compares the actual path of movement with an intended path of movement in order to control movement of the vehicle.

Brief Summary Text (9):
According to another aspect of the invention, a ground track sensor is provided which physically contacts the surface being traversed by the vehicle in order to sense relative movement between the AGV and the surface. The ground track sensor may include an unloaded wheel which does not bear any weight of the vehicle. The wheel preferably is a passive wheel which does not primarily steer or propel the automatic guided vehicle. Such ground-sensing wheel is rotatably mounted to the vehicle to rotate about a vertical axis and includes two precision encoders which monitor the angle of the wheel with respect to the vehicle's direction. Preferably, the wheel is mounted to the AGV with an arm that is pivoted with respect to the swiveling yoke. This allows a downward bias force to be applied to the mounting arms in order to provide firm engagement between the wheel and the floor irrespective of the irregularities in the floor.

Brief Summary Text (10):
The ground track sensor monitors movement of the AGV with respect to the floor and is capable of accurately measuring slippage laterally from the guide path from the angle and distance tavelled. This information is utilized by the navigation and control computer in order to augment the navigation information provided by the primary navigation system. According to another aspect of the invention, the primary navigation and control system includes a steered wheel odometry system

which measures the angle and distance travelled by one or more steered wheels. The navigation and control computer blends the outputs from the ground reference sensor and the steered wheel odometry system in order to compensate for any momentary interruptions in the operation of the ground-tracking sensor, such as may be experienced by a wheel encountering debris on the floor or the like. Additionally, the steered wheel odometry system may take the place of the ground track sensor when the vehicle is travelling in the reverse direction. The ground track sensor may be positioned anywhere on the underside of the vehicle or on an outrigger. A greater distance from the primary center of rotation of the vehicle provides greater resolution. However, sensor placement is possible even at the center of rotation of the vehicle, if sufficient sensor resolution is provided.

Drawing Description Text (2):
FIG. 1 is a side elevation of an automated guided vehicle (AGV) according to the invention towing a plurality of trailers;

Drawing Description Text (3):
FIG. 2 is a side elevation of the AGV in FIG. 1;

Drawing Description Text (7):
FIG. 6 is a plan view of an AGV illustrating layout and interconnection of major components of its navigation and control system;

Drawing Description Text (8):
FIG. 7 is a block diagram of the AGV navigation and control system;

Detailed Description Text (3):
Dead reckoning navigation--Navigation based upon sensing direction and distance travelled by the AGV. Examples include: (a) heading reference sensing, which measures rate of turn of the vehicle, and distance travelled, or (b) differential odometry, which measures differential rotation of spaced coaxial distance measuring encoders, and distance travelled, or (c) steered wheel odometry, which measures angle and distance travelled by one or more steered wheels; or a combination of these.

Detailed Description Text (4):
Heading reference sensor--An inertial sensor which provides a navigational computer with a measurement of an AGV's rate of turn.

Detailed Description Text (5):
primary navigation--Navigation utilizing (a) dead reckoning navigation or (b) sensing of a guide wire implanted in the floor along a desired path; or a combination of these.

Detailed Description Text (6):
Navigation computer--A computer-based system which continuously calculates the current position of the AGV based upon inputs from various guidance sensors.

Detailed Description Text (7):
System guide path--A virtual path laid out with respect to a floor. This is the intended path of travel of the AGVs and can have various branching.

Detailed Description Text (9):
Location verification system--Markers positioned at precise locations along the system guide path which are sensed by the AGV in order to verify, and compensate if necessary, the position of the AGV. This can include permanent magnets, plaques, transponders, code carriers, and the like.

Detailed Description Text (10):
Ground track sensor--A system that continuously senses actual movement of the AGV

with respect to the floor being traversed. Measures lateral travel, longitudinal travel, and/or rotation of the vehicle.

Detailed Description Text (11):
Referring now specifically to the drawings and the illustrative embodiments depicted therein, an automated guided vehicle (AGV) 10 is illustrated pulling a plurality of trailers 12 (FIG. 1). Each trailer 12 is typically loaded with materials, such as raw materials or finished components. Although the invention is illustrated with respect to such tugger AGV, its principles are applicable to AGVs in which the load is carried by the AGV per se.

Detailed Description Text (12):
AGV 12 includes a body 14 whose weight is supported by one or more rear drive wheels 16 and one or more forward steering wheels 18 (FIGS. 2-6). In the illustrated embodiment, two drive wheels 16 and one forward steering wheel 18 are utilized, although the invention is applicable to other combinations of driven and steered wheels. AGV 10 includes a local operator console 20 in order for the the vehicle to be manually operated and to be initiated into the AGV system. However, the AGV is typically under the control of a central control 21 which provides instruction to the AGV regarding its specified destination as well as the position and destination of other AGVs so that each AGV is capable of avoiding collisions with other AGVs. AGV 10 additionally includes a forward bumper 22 in order to sense impact with an object in the AGV's guide path and a hitch 24 in order to pull trailers 12.

Detailed Description Text (13):
Each AGV 10 is powered from a bank of batteries, located in a compartment 23, which supply an electric DC motor 26 associated with each drive wheel 16 through a motor control 27. AGV 10 additionally includes a ground track sensor, generally shown at 30, for continuously sensing movement of vehicle body 14 in the longitudinal direction of the vehicle as it travels along its guide path and rotation of the vehicle, as will be described in more detail below. In the illustrated embodiment, ground track sensor 30 includes a wheel 32 which is a non-load-bearing wheel with respect to vehicle body 14. Ground track sensor 30 additionally includes a support 34 for wheel 32 including a swivel joint 36 which attaches a yoke 38 for rotational movement about a vertical axis extending through a pin 40, which translates the rotational movement of the yoke to a pulley 44. Swivel 36 includes a bearing plate which is a machined ball brace. A pair of support arms 48, which are made of thick steel plate, support an axle 50 for wheel 32. Support arms 48 are pivotally mounted to yoke 38 by a yoke axle 52. Yoke axle 52 allows relative vertical movement of wheel 32 with respect to vehicle body 14. A spring 54 provides a downward bias to wheel 32 in order to maintain the wheel in constant contact with the floor. This is especially useful as the wheel runs over expansion cracks and objects on the floor so that the wheel maintains constant contact with the floor. Wheel 32 is made of a durable urethane material which both minimizes wear and provides adequate friction between the wheel surface and the floor. Additionally, this allows easy replacement of the wheel surface.

Detailed Description Text (14):
A distance-measuring encoder (DME) 56 is mounted to support arms 48 and interconnected with wheel 32 by a chain (not shown). Encoder 56 is connected electrically with a navigation and control computer 58 by a cable 60. A stationary stop 62a and a moveable finger 62b restrict rotation of yoke 38 to less than one revolution in order to protect cable 60. In the illustrated embodiment, encoder 56 provides 50 pulse-per-revolution accuracy in two quadrature channels which allows measurements of movement in both forward and reverse directions of the vehicle. In the illustrated embodiment, the encoder is used in only the forward direction of the vehicle thereby providing 100 pulse-per-revolution accuracy. As an alternative, the internal clock of the navigation and control unit may be utilized to provide interpolated pulses at 100 pulse-per-revolution in both forward and reverse

directions. Instead of using an encoder, distance may be measured by other distance measuring devices. Rotational movement of yoke 38 is transferred to a stationary precision encoder 42 by way of pulley 44 and a belt 46. Belt 46 is a cog-type timing belt in order to avoid misalignment between the pulley 44 and encoder 42. Encoder 42 is mechanically and electrically zeroed to a center position to within plus or minus 0.5 degrees of center. Encoder 42 is mounted by a bracket 64 which is adjustably mounted in order to allow tensioning of belt 46.

Detailed Description Text (15):
AGV 10 includes a vehicle navigation and steering control system 66 (FIGS. 6 and 7). System 66 includes a primary navigation system 68 which is a dead-reckoning sensing system. Primary navigation system 68 utilizes a heading reference sensor (HRS) 70, which is an inertial sensor which provides a measurement of the rate of turn of AGV 10. In the illustrated embodiment, heading reference sensor 70 is a spinning mass gyroscope marketed by Smith Industries Aerospace & Defense Systems, Inc. under Model No. 9190 A. However, other inertial sensors, such as fiber optic sensors, tuning fork sensors, and the like, may be utilized. Other dead-reckoning sensing systems could be used, such as magnetometer sensors, and the like, which sense heading of the vehicle. Primary navigation system 68 additionally includes a magnetic sensor 72 which is a location verification system. Magnetic sensor 72 senses magnetic markers which are positioned at precise locations along the system guide path in order to update the position of the AGV stored in navigation and control computer. The primary navigation system may additionally include a distance-measuring encoder (DME) 74 of a steering wheel assembly 76. Steering wheel assembly 76 additionally includes an angle encoder 78. DME 74 produces an output 80 which is supplied to navigation computer 58 that represents distance travelled by steering wheel 18. Angle encoder 78 produces an output 82 to a steering control 84 indicative of the angle of steering wheel 18 under the control of steering control 84. Ground track sensor 30 produces an output 86 to navigation and control computer 58. The output of ground track sensor 30 identifies ground track distance as well as the degree of the vehicle turn. Alternatively, distance could be measured by integration of measured velocity of the vehicle.

Detailed Description Text (17):
If slippage of AGV 10 is minimal, navigation can be done, utilizing standard dead-reckoning techniques, with primary navigation system 68 including heading rate sensor 70, distance travelled from DME 74 and turn angle from angle encoder 78. The output of heading rate sensor 70 is integrated in order to determine vehicle heading as follows:

Detailed Description Text (19):
The output of DME 74 (d.sub.s) and the output of angle encoder 78 (.theta.), along with an assumption of a fixed rotation point for the vehicle updates the location of the navigation point of the vehicle with respect to the floor. Equations 2 and 3 are incremental distances of the vehicle body 14, at point (0,0) in FIG. 8, which is the assumed vehicle velocity vector. Equations 4 and 5 integrate these components with the current (X, Y) position by rotating the distance travelled from body-based components to floor-based coordinate systems at the same time, as follows:

Detailed Description Text (20):
The invention is based upon the recognition that the assumption of minimal slippage is not always true. Although not limited to such applications, such slippage is especially present for tugger vehicles whose dynamics change drastically under loads applied to hitch 24. Varied plant floor conditions, such as wood block, steel and cement floors in the AGV, poor repair of the floor and debris, such as oil, grease, and scrap material, all add to the slippage problem. In particular, the loaded wheels, such as drive wheels 16 and steering wheel 18 are extremely susceptible to slippage. Sensors mounted on these points of the vehicle provide an opportunity for erroneous navigational information. The slippage makes the

assumption of a fixed vehicle rotation point invalid. Indeed, there are often cases where the actual rotation occurs about a point outside the vehicle, producing lateral translation rather than rotation.

Detailed Description Text (21):
This problem is cured, according to the present invention, by the addition of ground track sensor 30. Ground track sensor 30 is, in the illustrated embodiment, an unloaded, freely pivoting wheel which measures the distance travelled for the wheel and the angle the wheel has travelled with respect to the vehicle frame. Because wheel 32 does not have steering or load forces, these sources of error in sensor measurement are substantially eliminated. Additionally, its free-pivoting action allows simultaneous measurement of the vehicle rotation, movement along the longitudinal axis, and lateral translation. When this information is combined with outputs of the primary navigational system 68, both movement along the longitudinal axis and lateral translation of the vehicle can be resolved and applied to the floor position of the vehicle.

Detailed Description Text (22):
This compensation can be seen by reference to FIG. 8. This distance measured by ground track sensor 30 is transformed into body-based distances at point (0, 0) utilizing the location (L.sub.1x L.sub.1y) of ground track sensor 30 and the distance L.sub.2 of wheel 30 from pivot point 40. The effect of rotation of the vehicle, as measured by heading reference sensor 70, is then removed utilizing equations 6 and 7 as follows:

Detailed Description Text (23):
These distances are then translated to floor coordinates and summed to current plant-based X, Y positions according to equations 8 and 9 in order to arrive at an actual vehicle velocity vector, notwithstanding the presence of steer wheel slippage and/or traction wheel slippage.

Detailed Description Text (24):
It is seen by examination of equations 6-9 that the updating of the floor-based (X, Y) position of AGV 10 is a function of the heading of the vehicle, the angle of the ground track sensor, and the rotation of the ground track sensor. As such, the inputs from distance-measuring encoder 74 and the angle encoder 78 of the steering wheel assembly 76 are redundant. In one embodiment of the invention, the inputs from the steered wheel assembly are not utilized in the guidance and control of the AGV 10. Guidance of AGV 10 is a function of the readings of heading reference sensor 70 and ground track sensor 30 alone. In embodiments of the invention in which AGV 10 only travels in a forward direction, such guidance and control is sufficient. This embodiment allows ground track sensor 30 to be utilized with stops 62a, 62b which simplifies the structure of ground track sensor 30 by allowing use of a cable connection to the DME 56.

Detailed Description Text (25):
However, if AGV 10 is occasionally operated in a reverse direction, then the outputs of distance-measuring encoder 74 and angle encoder 78 of steering wheel assembly 76 are substituted for those of ground track sensor 30 when the vehicle is being driven in the reverse direction. This allows DME 56 to be utilized in a unidirectional rotation to increase resolution, as previously described. Although steering wheel 18 is a loaded and steered wheel, its performance at the rear of the vehicle, when the vehicle is being reversed, is superior to that of ground track sensor 30. In this reversing embodiment, ground track sensor 30 could be supplemented with a slip ring assembly, an inductive pickup, an optical data link, or the like, to pick up DME data while allowing yoke 38 to swivel in a full 360-degree rotation.

Detailed Description Text (26):
In an alternate embodiment of the invention, signals from encoders 42 and 56 of

ground track sensor 30 and the distance-measuring encoder 74 and angle encoder 78 of steering wheel assembly 76 are blended together even when vehicle 10 is operated in a forward direction. Such blended solution allows the navigation and steering control system to selectively ignore readings from ground track sensor 30 when such readings are invalid due to debris on the floor being traversed by wheel 32 and the like. The signals received from ground track sensor 30 and steering wheel assembly 76 are combined utilizing a Kalman filter, in a manner which would be readily apparent to those skilled in the art.

Detailed Description Text (27):
In the illustrated embodiment, updates in the position of AGV 10 are calculated at a 100 Hz update rate. The equations 6-9 are calculated with the assistance of a Model 80387 mathematic coprocessor of the type marketed by Intel Corporation or Cyrix Corporation. The present invention has been fully reduced to practice and successfully commercialized in an AGV marketed by Rapistan Demag Corporation, Grand Rapids, Mich., under Models DT-60 and DL-140. Although the invention has been illustrated with respect to a material handling AGV, it has broader application to on-road vehicle navigation, such as those utilized in commercial and personal vehicles, as well as control systems for off-road vehicles, including military vehicles, such as armored vehicles and the like.

CLAIMS:

1. An automated guided vehicle navigation and steering control system, comprising:

a primary navigation system which senses a heading or a rate-of-change of heading of an automated guided vehicle;

a ground track sensor which continuously senses relative movement of the automated guided vehicle with respect to a surface being traversed by the vehicle in order to determine an actual velocity vector of the vehicle; and

a navigation and control computer which is responsive to said primary navigation system and said ground track sensor for determining an actuated path of movement of the automated guided vehicle and for comparing said actual paths of movement with an intended path of movement in order to control movement of the vehicle.

3. The system in claim 2 wherein said ground track sensor includes a wheel in physical contact with the surface and does not carry substantially any vehicle weight and is a passive wheel which does not steer or propel the automated guided vehicle.

6. The system in claim 3 wherein said ground track sensor includes a yoke that is rotatably mounted to rotate about a vertical axis, an angle encoder which measures the radial position of said yoke with respect to said vertical axis, a wheel assembly attached to said yoke including a wheel mounted to rotate about a horizontal axis and a distance encoder measuring revolution of said wheel about said horizontal axis.

8. The system in claim 1 further including at least one driven wheel for propelling the automated guided vehicle and at least one steered wheel for directing the automated guided vehicle.

10. The system in claim 9 wherein said navigation and control computer is responsive to said steered wheel monitoring system for determining an actual path of movement of the automated guided vehicle when the vehicle is moving in a reverse direction.

15. An automated guided vehicle, comprising:

a body, at least one driver wheel for propelling said body along a surface, and at least one steered wheel for directing said body with respect to the surface;

a primary navigation system which senses a heading or a rate-of-change of heading of the body;

a distance measuring device which measures distanced travelled by said body in a longitudinal direction;

a ground track sensor which is independent of said wheels and which continuously monitors movement of said body with respect to the surface at least in a lateral direction; and

a navigation and control computer which is responsive to said primary navigation system, to said distance measuring device and to said ground track sensor for determining an actual path of movement of said body and for controlling said steering wheel in order to direct said body along an ideal path of movement.

17. The vehicle in claim 16 wherein said ground track sensor includes a wheel in physical contact with the surface and does not carry substantially any vehicle weight and is a passive wheel which does not steer or propel the automated guided vehicle.

19. The vehicle in claim 17 wherein said ground track sensor includes a yoke that is rotatably mounted to rotate about a vertical axis, an angle encoder which measures the radial position of said yoke with respect to said vertical axis, a wheel assembly attached to said yoke and including a wheel mounted to rotate about a horizontal axis, and a distance encoder measuring revolution of said wheel about said horizontal axis.

21. The vehicle in claim 20 wherein said navigation and control computer is responsive to said steered wheel monitoring system for determining an actual path of movement of the automated guided vehicle when the vehicle is moving in a reverse direction.

25. An automated guided vehicle comprising:

a body, at least one driver wheel for propelling said body along a floor, at least one steered wheel for directing said body with resect to the floor, and a steered wheel monitoring system which monitors steering angle of said at least one steered wheel;

an inertial navigation sensor which senses rate-of-change of heading of said body;

a ground track sensor which monitors a ground velocity vector with respect to said body independent of said wheels; and

a navigation and control computer which is responsive to said inertial navigation sensor and to said steered wheel monitoring system and said ground track sensor for determining an actual path of movement of said body and for controlling said steering wheel in order to direct said body along an ideal path of movement.

26. The vehicle in claim 25 wherein said navigation and control computer determines an actual path of movement of said body in response to said ground track sensor when the vehicle is moving in a forward direction.

27. The vehicle in claim 25 wherein said navigation and control computer determines an actual path of movement of said body as a blend of said ground track sensor and said steered wheel monitoring system.

28. The vehicle in claim 25 wherein said navigation and control computer determines an actual path of movement of said body in response to said steered wheel monitoring system when the vehicle is moving in a reverse direction.

29. An automated guided vehicle comprising:

a body, at least one driver wheel for propelling said body along a floor, and at least one steered wheel for directing said body with respect to the floor; and

a body-based inertial navigation system which senses actual movement of said body in at least three degrees of freedom irrespective of side slippage of the vehicle.